Transactions

AMERICAN FOUNDRYMEN'S ASSOCIATION

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TRANSACTIONS

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Improvements in Gas Melting Furnaces in the Non-Ferrous Foundry

By E. W. Williams*, Pittsburgh, Pa.

Abstract

The author outlines what he believes to be the ideal melting furnace for a non-ferrous foundry to give a maximum control of melting conditions. He divides non-ferrous melting furnaces into two classes, crucible and open-flame. The ideal furnace, according to the author, is one which will deliver metal of uniform analysis at uniform temperature, heat after heat, would have endless operating life and would operate at minimum cost. He then gives directions for building both crucible furnaces of the stationary and tilting types and pear-shaped, open-flame furnaces which approach the ideal closely. With these furnaces, melting time, scrap losses, melting loss, and fuel consumption were reduced and furnace life was increased.

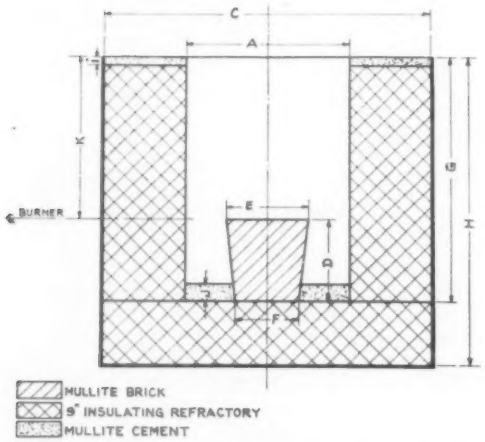
1. This paper deals with furnaces for the melting of non-ferrous metals, mainly brass and its cousins. Although, there has been little change in the specifications of brass and bronze since the founding of this country, the practice of melting the charge has undergone considerable change.

2. If we were to design an ideal furnace for the melting of copper and its alloys, it would be one that would deliver metal of uniform analysis at a uniform temperature, heat after heat. Second, it would have an endless operating lifetime, and third, would operate at a minimum cost. Such a furnace you say is impossible, but let us see how near we can approach the ideal.

3. To deliver metal of uniform analysis at a uniform temperature, we must assume the conditions outside the furnace and the conditions within the furnace do not vary from heat to heat. Second, that the same weight and nature of the charge is fed to the

* Equitable Gas Co.

Note: This paper was presented at a Non-Ferrous Session of the 44th A.F.A. Convention, May 7, 1940, Chicago, Ill.



FURNACE DIMENSIONS IN INCHES										
CRUCIBLE NO.	A	B	C	D	E	F	G	H	J	K
40	14		32	8	7½	5½	22	29	1½	
45	15		33	8	7½	5½	22½	29½	1½	
50	15½		33½	8	7½	5½	23½	30½	1½	
60	16		34	8	9	7	24	31	1½	
70	16½		34½	8	9	7	24½	31½	1½	
80	17		35	8	9	7	25	32	1½	
90	17½		35½	9	9	7	26½	33½	1½	
100	18		36	9	9	7	27½	34½	1½	
125	19		37	9	9	7	28	35	2	
150	20		38	9	10	7	29	36	2	

FIG. 1—STANDARD GAS-FIRED CRUCIBLE FURNACES, TILTING TYPE.

furnace, and third, that a heat medium of uniform calorific value is used. Then, it would be possible to deliver metal of uniform analysis at a uniform temperature, and, furthermore, each heat should be taken from the furnace in the same period of time.

4. The varying conditions outside the furnace are temperature and humidity, which should affect our results very little. The conditions inside the furnace are mainly gases formed by the oxidation of the lining, and gases formed from imperfect combustion. The gases formed by the oxidation of the lining can be eliminated by the use of proper lining materials. The gases from imperfect combustion can be eliminated, provided a fuel of constant heat value is used.

5. The second condition, that of an endless operating lifetime means a refractory that will not burn out. We know of no such lining material today, although, the refractory manufacturers are producing satisfactory lining materials.

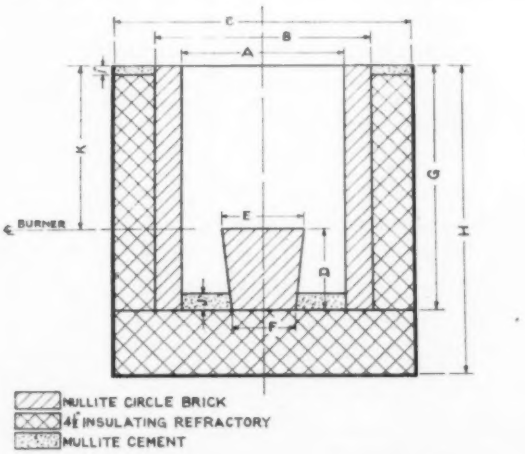
6. The third calls for a heating medium of uniform calorific value, and, which is readily available. The use of gas, when mixed with the proper amount of air, and this mixture controlled properly, will supply constant heat to the furnace efficiently and economically. So, it is possible to construct a furnace that does approach the ideal.

7. The author will discuss the two most common types of furnaces used in the melting of non-ferrous metals. First, crucible furnaces and second, open-flame furnaces.

CRUCIBLE FURNACES

8. Crucible furnaces may be divided into two types: (1), Tilting (Fig. 1) and (2), Stationary (Fig. 2).

9. Through the cooperation of the furnace manufacturers and the combustion engineers of the gas companies, and the fact that some non-ferrous foundries permitted us to use their plants as a



FURNACE DIMENSIONS IN INCHES										
CRUCIBLE NO.	A	B	C	D	E	F	G	H	J	K
40	14	20	29	8	7½	5½	22	29	1½	
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50	15½	21½	30½	8	7½	5½	23½	30½	1½	
60	16	22	31	8	9	7	24	31	1½	
70	16½	22½	31½	8	9	7	24½	31½	1½	
80	17	23	32	8	9	7	25	32	1½	
90	17½	23½	32½	9	9	7	26½	33½	1½	
100	18	24	33	9	9	7	27½	34½	1½	
125	19	25	34	9	9	7	28	35	2	
150	20	26	35	9	10	7	29	36	2	

FIG. 2—STANDARD GAS-FIRED CRUCIBLE FURNACES, STATIONARY TYPE.

proving ground, considerable improvement has been affected in the past several years.

10. The five factors which contribute most to the economics of melting in the crucible type furnace are:

1. Time to get out a heat.
2. Cost of the fuel.
3. Metal loss.
4. Life of the lining.
5. Life of the crucible.

Design of Crucible Furnaces

11. Let us consider the design of the modern crucible furnace. The inside diameter of the furnace is arrived at by taking the diameter of the crucible at the bilge and adding 5½-in., leaving a space of 2¾-in. between the crucible and the furnace wall. This space seems most desirable for quick and efficient heating and serves two purposes: first, as a passage for the movement of the hot gases around the crucible, thus imparting heat into the crucible by convection and at the same time heating the crucible by radiation from the side walls. The second reason is that it acts as a clearance for the insertion and removal of the crucible.

12. The later furnaces are built of light weight refractory. Such a refractory cuts down heat losses, speeds melting time and thus saves fuel. In the tilting type furnace, a 9-in. wall is recommended. To obtain the outside diameter of the furnace then, we add 18-in. The inside face of this brick should be washed with a solution of air setting cement, so that the hot gasses will not penetrate into the pores of the brick.

13. This light weight refractory will not stand abrasion so the walls of the stationary furnace must be constructed differently. The refractory manufacturers recommend a burned inner lining of silicon carbide, mullite or sillimanite 3-in. thick. A neutral lining is more satsfactory where a basic flux is used, thus insuring no chemical reaction between the lining and the flux. This inner face lining is backed up by 4½-in. of light weight refractory. Thus, to get our outside diameter of the stationary furnace, we add 15-in.

14. The height of the furnace is arrived at by starting the top of the furnace 2-in. above the top of the crucible and adding the

overall height of the crucible + the recommended height of the stool and allowing 7-in. for the bottom insulation. Two-in. of silicon carbide, directly over the bottom to catch any spillage of metal, is recommended. A hole 2-in. in diameter, with a downward slope, is made in the side directly over the bottom, so that any spillage of metal will drain out of the furnace.

Burners

15. Through experience it was found that a multiplicity of burners gave more satisfactory results than a single burner. A recommended practice is:

Two burners for furnaces up to No. 100 crucible.

Four burners for furnaces over No. 100 crucible.

16. The burner nozzles fire tangentially. Some engineers recommend that the burners be placed in the same plane at the junction of the stool and the crucible. The author believes, that when the burners are staggered, a more even temperature is attained, hot zones are eliminated, therefore, a longer crucible life should result.

17. The air and gas are supplied to the furnace through a proportioning mixer and tunnel type burners. The fundamental principle of the proportioning mixer is such that when the correct ratio of air and gas has been set to meet the operating conditions, that mixture remains constant over the entire range of the burner capacity thus eliminating the human element. The proportional mixer is a two-pipe, one-valve control combustion system requiring air at 1 to 1½ lb. per sq. in. pressure and gas at a pressure of 2 to 6-in. of water.

18. Air, under pressure, enters the air inlet and passes through the constricted throat where its static pressure is transformed completely to velocity pressure. The high velocity air creates a suction at the gas port. Suction at the gas port causes the gas, at constant atmospheric or zero pressure, to flow through the port into the mixer where it is thoroughly mixed with the air. A static pressure of the mixture is built up in its passage through the inspirator body. The governor reduces the pressure of the incoming gas to a constant atmospheric or zero pressure. The air gas ratio is set by adjusting the gas port, and after this adjustment is once made for a specific kind of gas and combination of burner area, this fixed ratio of gas and air will be maintained over the entire

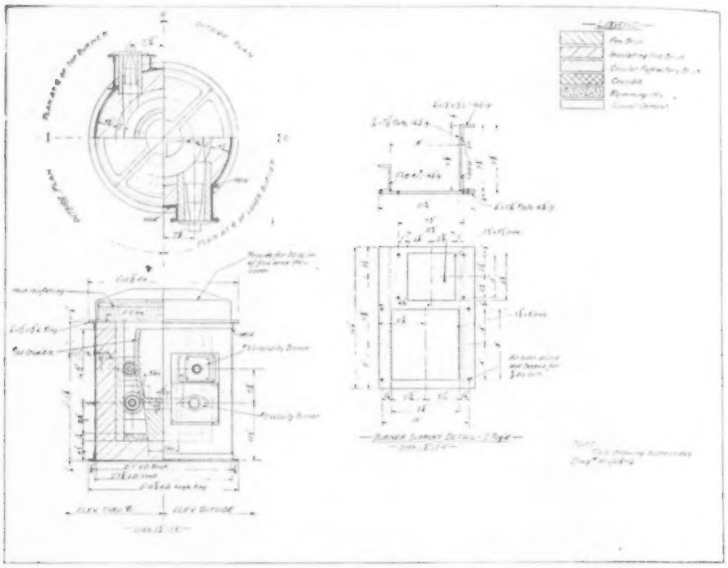

FIG. 3—NO. 150 STATIONARY CRUCIBLE FURNACE.

range of the inspirator. The quantity of heat flow is controlled by regulating the air valve. A tunnel type burner, which does not set up a high temperature in the tunnel, is recommended.

19. The air should be supplied by a constant pressure blower. A manometer is placed on the manifold.

20. With this installation any previous operation can be duplicated.

Melting Loss

21. It has been found from tests that with a furnace as outlined and the use of gas as a fuel, a reduction of 50 per cent metal loss will result as compared to good oil practice and 33⅓ per cent as compared to the use of solid fuel. The reduction of metal loss where gas is used as a fuel is a result of (1) faster heating, (2) control of atmosphere, (3) a lesser volume of flue gases swirling over the metal and (4) less temperature difference existing in different parts of the furnace.

Crucible Life

22. The life of the crucible is decidedly dependent upon foundry practice. Variations from 30 to 200 heats per crucible

have resulted in the same furnace using gas as a fuel. By foundry practice, I refer to such factors as improper annealing, abusive handling with tongs, careless use of pokers, leaving hot crucibles in cold air drafts, etc. Crucible life has been materially increased with the use of gas fuel due to a low thermal head, and by more even heating of the crucible.

23. A test on No. 150 crucible furnace (Figs. 3 and 4) gave the results shown in Table 1.

Table 1

TEST ON NO. 150 TILTING TYPE FURNACE MELTING 85-5-5-5

Time In	Time Out	Minutes	Meter Reading Start	Meter Reading Finish	Total Consumption	Cubic ft. per lb.	Temp., °F.	Weight of Metal, lb.
7.45	9.00	75	145650	147045	1395	3.1	2150	450
9.15	10.05	50	147045	148215	1170	2.6	2160	450
10.05	10.50	45	148215	149340	1125	2.5	2180	450
11.00	11.45	45	149340	150285	945	2.2	2150	450
12.30	1.30	60	150285	151355	1075	2.4	2160	450
1.40	2.25	45	151355	152360	1005	2.37	2170	450
2.30	3.10	40	152360	153305	945	2.1	2160	450
3.15	3.55	40	153305	154235	930	2.07	2140	450

Pounds metal melted	3600
Cu. ft. gas consumed	8585
Cu. ft. gas per lb.	2.38
Per Cent Metal loss	1.4

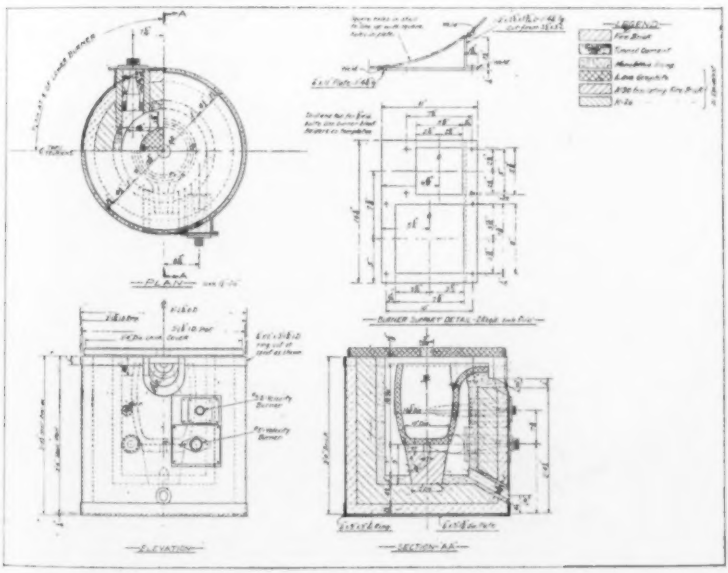

FIG. 4—NO. 150 TILTING TYPE FURNACE.

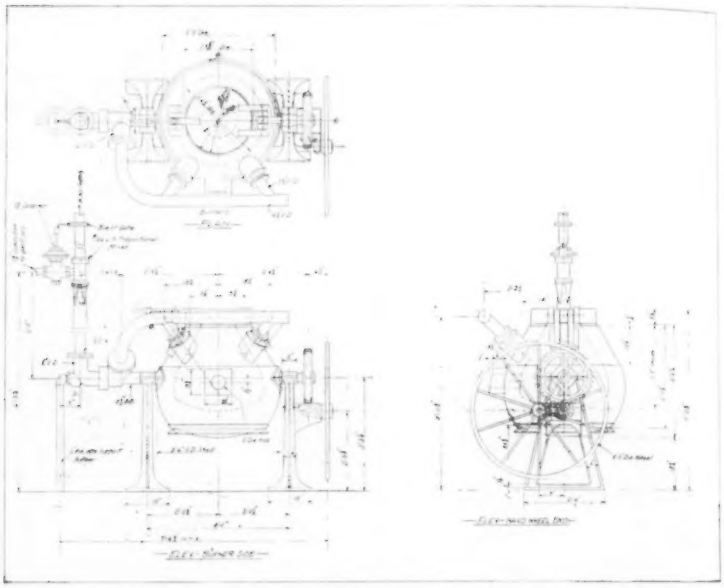

FIG. 5—42-IN. OPEN-FLAME FURNACE OF 1000 LB. CAPACITY.

OPEN FLAME FURNACES

24. In the Pittsburgh area, there are probably more open-flame furnaces in operation than any other type of furnace.

25. The open-flame furnace may be divided into two types:

(1) Barrel Shaped Furnace

(2) Pear Shaped Furnaces

26. The writer has had very little experience with the barrel-shaped furnace and would hesitate to discuss this furnace at length.

27. A brass foundry in the Pittsburgh district has a battery of 42-in. "open-flame," pear-shaped furnaces (Fig. 5) with a melting capacity of 50,000 lb. per day. These furnaces were originally fired with oil but were gradually changed to gas. The original combustion equipment consisted of two sealed in burner tuyeres and the air and gas were supplied through a mixing tee with individual valves in the air and gas lines.

28. The method of operation was to preheat the furnace for 45 min. in the morning. The furnace was then charged with approximately 650 lb. of metal. An average charge consisted of 40

per cent ingots, 45 per cent gates and risers and 15 per cent virgin metal. The standard time of melt was 55 min.

29. While studying the operation and control of these furnaces, we noticed that the combustion was entirely dependent upon the operator. It was necessary to preheat the furnace with raw gas before any air could be turned on. The character of the flame would change during a heat, due to a change in air or gas pressure. It required constant supervision of the attendant. Although, the weight and makeup of the charges for each heat were the same, it was very difficult to duplicate results.

30. After carefully studying the operation of these furnaces, we believed that a more positive and efficient method of firing these furnaces, could be effected. With the plant engineer and the metallurgist, we reviewed carefully the records of the castings for the previous year. The loss by rejected castings was abnormally high. It was concluded that the percentage of rejects could be materially reduced by an improvement in melting practice. It was decided to turn the problem over to the writer to see if a more efficient method of firing these furnaces as well as a more positive method of atmosphere control in the furnace could be adopted.

Furnace Efficiency Tests

31. An efficiency and metal loss test was conducted with the results shown in Table 2.

FIG. 6—A BATTERY OF OPEN-FLAME FURNACES IN OPERATION.

Table 2

RESULTS OF EFFICIENCY AND METAL LOSS TESTS

Type of metal melted, 78 per cent Copper, 21 per cent Tin, 0.25 per cent Zinc, 0.75 per cent Lead.

Metal Melted, lb.	7,979
Gas used, cu. ft.	19,255
Cu. ft. per lb.	2.41
Per Cent metal loss	1.66

32. After considerable study and investigation of the different types of combustion equipment available, it was decided to equip one furnace with—

Two sealed in tunnel type burners.

One proportioning mixer.

Constant pressure blower. 24 oz. delivery pressure.

Manifold pressure gauge.

33. Undoubtedly the most important factor of good combustion and in securing fuel economy is the maintenance at all times of the correct ratio of air to gas. For complete combustion, there is a fixed volume of air required for each volume of gas burned. With this type of mixer, once that ratio is set, proper combustion is not dependent upon the human element. Any desired furnace atmosphere, whether reducing, oxidizing or neutral can be maintained.

34. The manifold was raised high enough to install the regulation tunnel on the burners. This was done by welding a collar 8-in. in diameter and 8-in. long, over the burner holes and flanging the manifold onto these collars. A manometer was placed on the manifold so that any operation could be duplicated.

35. After the furnace was lighted, a peculiar shrill whistle developed. Straightening vanes were placed in the manifold ahead of each burner. This eliminated the noise.

36. A charge of brass turnings was placed in the furnace and after 1 hr. and 10 min. of heating, a temperature of 1960°F. was all that was attained with an approximate gas consumption of 4 cu. ft. per lb. of metal. After several heats were tried with the same result, it was decided that the conventional tunnel type burner localized the heat around the discharge end of the tunnel. After

considerable study, a velocity type nozzle was designed and installed. A specially designed tunnel was rammed in place.

37. A charge of cuttings was then melted in 40-min. and a temperature of 2180°F. was attained with a gas consumption of 2.2 cu. ft. per lb. of metal.

38. As the largest percentage of rejects were cast from metal having an analysis of 78 per cent copper, 21 per cent tin, 0.25 per cent zinc and 0.75 per cent lead, it was decided to limit the investigation to this metal.

39. Tests were conducted to:

1. Ascertain effect of atmosphere.
2. Effect of pouring temperature.
3. Manifold pressure.

40. To determine possible productive capacity as well as the effect of fast melting on fuel economy and metal loss, a test was run on one furnace melting that metal. On a full day's run of 8 hr., a melting time of 25 min. was required for an average charge of 585 lb. with an overall gas consumption of 1.52 cu. ft. of 1120 B. t. u. natural gas per lb. of metal. This included the original warming up of the furnace. The metal loss was approximately 0.7 per cent. This was with an uninsulated furnace, the lining being 7-in. of a mixture of high grade fire clay and ganister.

Pouring Temperature and Furnace Atmosphere on "Pin Hole" Porosity.

41. By the adjustment of the proportioning mixer, the fuel mixture was made oxidizing. The furnace was charged with 588 lb. of metal and heated to 2050°F. Eight castings were made. The balance of the metal was heated to 2250°F. and eight castings were made at this temperature.

42. The mixture was then made reducing and the same test as above conducted.

43. The results of this test are shown in Table 4.

44. In continuance of these tests, it was ascertained that pouring temperature was a very vital factor of good castings. These tests also showed that a slightly oxidizing atmosphere was desirable.

45. After the furnace had been in operation for a period o.

Table 3

TESTS CONDUCTED

Test No. 1

Conducted to ascertain:

(a) Correct furnace atmosphere.....Slightly oxidizing
(b) Proper manifold pressure.....9-in. of water
(c) Proper pouring temperature.....2040°F.—2080°F.
(d) Time necessary to melt.....35 min.

Efficiency and Melting Loss

Test number.....	2	3	4	5
Number of Heats per Day.....	9	8	10	13
Pounds of Metal Melted.....	5307	4705	5880	7644
Cu. Ft. of Gas Consumed.....	11200	10590	10800	11640
Cu. Ft. Gas per lb. of Metal....	2.10	2.20	1.80	1.50
Avg. Time to Melt.....	35 min.	35 min.	30 min.	25 min.
Max. Temperature.....	2080°F.	2060°F.	2080°F.	2090°F.
Min. Temperature.....	2040°F.	2050°F.	2060°F.	2070°F.

NOTE: A melting loss was conducted on test No. 3 with actual melting loss of 0.70 per cent. The progressive increase in efficiency was the outcome of experimenting with our manifold pressure and shows very clearly the possibilities of this type of control on an open-flame furnace of the type indicated.

time, and the operators had become familiar with the operation, it was possible to reduce the time of melting. By adopting a manifold pressure, it was possible to pour each heat in the same period of time within 10 degrees of the desired temperature.

46. A complete analysis had proved to the metallurgical department the fact that castings of this metal could be produced in an open flame furnace provided atmosphere, time in the furnace and casting temperatures were controlled. Sufficient work had been done to convince everyone concerned that with this type of combustion system, the above mentioned factors could be controlled. The simplicity of operating the proportioning mixer practically eliminates the human element from the melting cycle. This, the author believes, is of major importance in successfully controlling melting practice.

Table 4

RESULTS OF POROSITY TEST

Test No.	*Mixture*	*Temp. °F.*	*Fracture*	*After Machining*	
				Good	*Bad*
2A	Lean	2050	Good	7	0
2B	Lean	2250	Bad	0	7
3A	Rich	2050	Good	7	0
3B	Rich	2250	Bad	0	7

47. Possibly the feature that appeals most strongly to plant management is the ease and accuracy with which these furnaces may be controlled. A water column or manometer shows the pressure of the fuel (air-gas) mixture being sent to the burners. So accurate is the control of these units that it is standard practice to specify that for a given metal composition and weighed charge, the furnace shall be run for a definite number of minutes at a stated mixture pressure. At the end of this period, the metal is ready to pour. Pouring temperatures are thus obtained with regularity within 10 degrees of one another.

48. Another important consideration is the very fact that the metal can be removed from the furnace quickly. Authorities on the subject agree that the quicker any non-ferrous metal can be melted and removed from the furnace, the better the quality.

49. As a result of this work, all 17 furnaces were changed. Tests were conducted on a metal with an analysis of 81 per cent copper, 2.50 per cent tin, 6 per cent lead and 10.50 per cent zinc.

50. Although a test covering 60 heats showed a metal loss of 1.89 per cent, the plant metallurgist feels that 2.25 per cent loss is to be expected in plant operation.

51. A comparison with their previous practice is shown below.

Old Practice One Blower	3 cu. ft. Gas per lb. 3 per cent Metal Loss Time, 60 Min.
Individual Blower	2.5 cu. ft. Gas per lb. 2.5 per cent Metal Loss Time, 55 Min.
Present Practice	2.25 cu. ft. Gas per lb. 2.25 per cent Melting Loss Time, 40 Min.

52. The plant metallurgist has done a good job in ironing out other factors, such as proper core and ladle drying, pattern design and molding practice. Although a high percentage of their castings are pressure castings, less than 2 per cent are rejected because of porosity.

53. Many factors are involved in the efficient and economic operation of a non-ferrous foundry. Proper supervision, the scheduling of molders and furnaces, core and molding practice, ladle drying, etc. If these factors are controlled, a uniform quality of metal at a uniform temperature in the same period of time can be produced in a properly designed gas fired furnace.

DISCUSSION

Presiding: R. W. PARSONS, Ohio Brass Co., Mansfield, Ohio.

G. K. EGGLESTON[1]: The crucible furnace described by Mr. Williams has gone a long way toward improving gas melting. I do not believe the ultimate has been reached by any means, but I think we are getting a little nearer to it.

I have no fault to find with the figures presented by the author, as far as the gas furnaces are concerned, but in paragraph 21, where comparisons between gas furnaces and oil-burning furnaces are given, he states—"It has been found from tests that with a furnace as outlined and the use of gas as a fuel, a reduction of 50 per cent metal loss will result as compared to good oil practice. The reduction of metal loss where gas is used as a fuel is a result of (1) faster heating, (2) control of atmosphere, (3) a lesser volume of flue gases swirling over the metal and (4) less temperature difference existing in different parts of the furnace." I rather doubt the accuracy of that statement.

In the paper presented by W. B. George, "*Melting of Copper-Base Alloys to Retain Physical Properties*,"* Table 1 gives what he considers the fuel consumption under good melting practice. The figures given for tilting crucible melting with oil agrees almost exactly with Mr. Williams figures for gas in his furnace, when compared on a B.t.u. basis.

I will agree that it is much easier to maintain the desirable atmosphere with gas, but it can be done with oil. The combustion chamber design may have to be changed; in that respect many of the present oil burners are very inefficient, but they can and have been improved and for the most part made as efficient as gas.

As far as faster heating goes, I believe oil might be the faster due to the flame temperature of oil being higher than most gases. Temperature differential existing in different parts of the furnace is a matter of furnace design and can be eliminated with oil as well as with gas.

If my memory serves me right, I do not believe it requires any more air to burn 1000 B.t.u. of gas than it does oil, or that there would be any great difference in the volume of the products of combustion.

[1] Metallurgist, Detroit Lubricator Co., Detroit, Mich.

* TRANSACTIONS, American Foundrymen's Assoc., vol. 48, pp. 141-160, Sept. (1940)

SAM TOUR[2]: I take it that all of this work is in connection with the use of natural gas. Is that 1100 B.t.u. gas?

MR. WILLIAMS: Yes.

SAM TOUR: It must be borne in mind that all these figures with regard to gas consumption fall down if a change is made to some other type of gas. If these are based on 1100 B.t.u. gas, natural gas, they are based on using a gas that is practically all methane, CH_4.

Methane, CH_4, consists of 1 part carbon and 4 parts hydrogen, and burns to form 1 volume of carbon dioxide and 2 volumes of water. In the products of perfect combustion there are present 10 parts of carbon dioxide and 20 parts of water vapor. It is water that causes gassing of metal and makes necessary the operation on the oxidizing side.

When burning a fuel that does not burn to water, it is not necessary to stay on the oxidizing side. Coke-fired pit furnaces have a reducing atmosphere, high in carbon monoxide CO and an oxidizing atmosphere is not necessary because no water vapor is being formed by the combustion reaction.

Suppose a change is made from natural gas that burns to twice as much water as carbon dioxide to another form of gas, say propane gas, C_3H_8. Propane gas burns to produce three volumes of carbon dioxide and four volumes of water. The ratio of carbon dioxide to water has been changed and all the furnace conditions are changed accordingly.

If fuel oil is burned, the ratio is further changed and less water is formed than carbon dioxide. These changes cut down that troublesome element, water, in the product of combustion. Water is the component that leads to gassing troubles.

I disagree with Mr. Williams' statement and agree with Mr. Eggleston about fuel efficiency and melting losses. Fuel oil is no less efficient and does not give higher melting losses. A change from natural gas to oil is a change to something that burns to less water and is less liable to cause trouble due to gassing. Less oxidizing conditions are necessary and lower melting losses are attainable.

Improved design of gas furnaces should be compared to well-designed oil-fired furnaces with proper burner arrangement and proper proportioning of air to oil. On this basis, what Mr. Williams has shown is possible with gas becomes even more possible with oil.

HAROLD J. ROAST[3]: We have a plant in which we use natural gas. In two other plants, we use oil and in another coke so that we have comparative statements readily available. We do find that we should agree with Mr. Eggleston on the subject of oil, while obviously still getting good results from gas.

I do believe, as the result of listening to the last part of this paper, that we can improve our results from natural gas. But melting, as we are now, in one plant about a million pounds a month with oil,

[2] Vice president, Lucius Pitkin, Inc., New York, N. Y.
[3] Vice president, Canadian Bronze Co., Ltd., Montreal, Canada.

open flame furnaces, we find we get very excellent results. We have been working on the oil furnaces for about four years in regard to improving the combustion. We did not accept the original oil burner and leave it at that. I would not like to see the oil relegated to a condition of being only half as good as gas. I should like to see both of them twice as good as they are.

MEMBER: Relative to paragraph 51 in this paper showing individual blowers for each furnace giving considerable higher efficiency than the common blower, would the author explain that?

MR. WILLIAMS: The single blower was a variable pressure blower. This blower furnished air to eight furnaces. As a furnace was turned off or another furnace lighted, the air pressure would change, thus changing the combustion condition in the other furnaces. With an individual blower delivering air to one furnace, this condition would be eliminated.

MEMBER: In connection with the burner design of the smaller furnace, the author mentioned that a staggering of the burners was advantageous. Would he recommend two burners situated at opposite sides at the same level or two at the same side staggered one above the other?

MR. WILLIAMS: In the smaller furnaces, we place one burner at the junction of the crucible and the stool. The other burner, at 180 degrees from the first burner, is placed slightly higher. We put about 60 per cent of the fuel on the burner firing at the junction of the stool and crucible and about 40 per cent on the burner firing a little bit higher.

We find by doing that we do not develop a high bottom temperature but get a more even temperature from the bottom to the top of the crucible.

MEMBER: In some designed furnaces there is a swelling of the furnace at the bottom of the crucible. Is that of any great advantage?

MR. WILLIAMS: Not that I know of. It may speed the velocity of the gasses around the crucible. A better scrubbing action might be developed. We have not gone to that form of design.

In the investigation of gassed metal, we designed a crucible furnace so that the products of combustion did not come in contact with the metal. The side walls were constructed of 9-in. insulating refractory and a cast inner lining of sillimanite 2-in. thick. This inner lining was interlocked with the insulating brick in a way to make a stronger mechanical furnace.

A seal was provided between the furnace chamber and the top of the crucible. The flues were taken out through the side walls below the top of the crucible. Although the products of combustion did not come in contact with the metal, the metal was of no better quality than the metal produced in the open flame furnace.

Report of Technical Director, Foundry Sand Research Committee

By Dr. H. Ries, Ithaca, N. Y.

It has commonly been the custom for the Chairman of the Foundry Sand Research Committee to make a report annually, informing members of A.F.A. of any action which the Committee has taken during the preceding 12 months. While the writer shall not neglect this point, there are several other matters to which he desires to draw attention.

It is now nearly 19 years since the Foundry Sand Research Committee came into existence. The importance of sand properties was realized at that time, and efforts had been made to evaluate some of them.

However, it is safe to say that it was not until the Foundry Sand Research Committee began work that we appreciated how important the sand properties then known to us might be; how little we really knew about them; and, as it subsequently developed, that there were additional properties which had been overlooked.

Perhaps this last point is one of the reasons why the Committee is still on its job. The General Committee and its subcommittees began seriously to develop methods for testing sand properties. Every test was tried out before it was publicized. It was at first recommended as a tentative standard, and not passed as a permanent standard until it had undergone the scrutiny of both friendly and hostile critics for at least a year.

Those tests which have been recommended by the Committee are included in the A.F.A. Handbook on *"Testing and Grading Foundry Sands and Clays,"* now in its fourth edition. Any others which may be recommended before the appearance of a new edition will be published in *American Foundryman.*

There are also some tests which have been used by individuals, and referred to in the literature, but which have not thus far been recommended by the Foundry Sand Research Committee.

The original function, which all tests were supposed to serve, was that of enabling the foundryman to keep track of the condition of the sand in his heaps and systems, and if these were not suitable, to be able to correct them. This then led to the use of these tests for sand control, and for this purpose the writer thinks everyone recognizes their value. Since, however, the tests serve to show the qualities of the sand, some foundrymen make use of them to specify the character of the material which they order.

Committee Does Not Make Specifications for Materials

It should be recognized that it is *not* the function of the Foundry Sand Research Committee to set up specifications for materials. It *is* the duty of the Committee to specify the conditions that a piece of apparatus must meet to correctly evaluate properties of sand. Further, it is *not* the function of the Committee to recommend one type of apparatus over another.

If any foundry desires to use, for specification purposes, the properties as determined by tests, it is entirely a matter of its own concern. Many foundries do this, and, so far as the writer is able to ascertain, there have been few objections from the producer.

The Committee on Sand Research realizes that some of the tests might be improved, and efforts to accomplish beneficial changes are now under way. There have been cases where some test has been strongly condemned, but it has usually been found that in such instances the fault lay with the operator and not with the test or apparatus.

COMMENTS ON TESTS AND APPARATUS

Testing Apparatus—Although the testing of sands is now being widely used, it should be more extensively employed. Apparently some members of the industry feel that the apparatus now on the market is rather expensive. The Committee is always open to suggestions for simplification of apparatus which will enable it to be made and sold more cheaply, so that more foundries can make use of it, keeping in mind the necessary accuracy of the particular instrument involved.

On some occasions, an ingenious foundryman develops a set of home-made apparatus which appears to meet his needs. Mention might here be made of the Hercules Foundries, Inc., Los Angeles, Calif., that has such a set, the total cost of which was about $20.00. It is used for daily sand control, including the determination of moisture, green compression and permeability. The foundryman using it cannot check with any other foundry in terms of standard units, but for his own work, it gives fair satisfaction and he deserves to be complimented for his ingenuity. This apparatus has been described in the *American Foundryman*, August, 1940.

Fineness test—This involves two features, *viz.* (1) The separation of the grain into different sizes by means of sieves, and (2) determination of A.F.A. clay.

The Foundry Sand Committee of the National Industrial Sand Association has been giving considerable attention lately to the separation of the different-sized sand grains by sieves, and the fact that different laboratories do not always get a close agreement when even the same sand sample is tested by them.

The writer thinks it is safe to say that the disagreements are usually not great. Where there is a marked exception shown, this may be so large as to suggest that something is wrong with the technique,

sieves, or method of taking sample. The fact that different laboratories sometimes differ markedly, has led to the proposal that we should eliminate the suggested tolerance figures in our purchase forms.[1] As the writer reported last year, this has been done, leaving the adjustment to producer and consumer. Curiously enough these suggested tolerances above referred to are larger than most of those which the writer has seen in specifications issued by consumers. Attention is also called to the fact that the purchase forms referred to above are recommended only as a guide to purchasing and are not standard.

It may be added that the A.F.A. is cooperating with the Foundry Sand Committee of the National Industrial Sand Association.

All foundries do not use certified sieves, and it will be interesting to ascertain whether this makes much difference in the results. In addition to studying sieve tests of silica sands, the Foundry Research Committee of the National Industrial Sand Association is also studying the results obtained by testing samples of the same naturally bonded molding sands in different laboratories.

Life of Sieves—There is no doubt that some sieves become inaccurate through use. This might be due to (1) Holes in the mesh or tears around margin of the sieve which might go unnoticed in the hands of a careless operator; (2) spreading of the meshes due to improper methods of cleaning the sieves; (3) excessive blinding of the sieves; or (4) wearing of the wires.

In this connection, the writer has attempted to get some accurate data on the life of sieves. One series of figures supplied me showed that a 200 mesh sieve seemed to be in good shape after a year's use.

The Soil Conservation Laboratory, Pasadena, Calif., states that its sieves are calibrated with a standard sand sample that is kept on hand. The writer is informed by G. H. Otto that "With our present rules for cleaning sieves, I fully expect an average sieve life in excess of 1,000 analyses for sieves finer than 1 mm. opening," and, "Sieve life is undoubtedly connected with sieving time, sample weight, as well as mode of cleaning."

A third operator reports that they get approximately 18 months service per set, running probably six samples daily.

The coarser meshes seem to wear more rapidly, as several operators have testified.

A.F.A. Clay Determination—The determination of the A.F.A. clay presents another problem. It is argued by some that the time required for washing out the clay by the settling and siphoning method is altogether too long, although even here the period required seems to vary greatly with different operators.

Let me call your attention to several short-cut methods which are used.

[1] Standards and Tentative Standards for Testing and Grading Foundry Sands and Clays, 1938 edition, pp. 83-84.

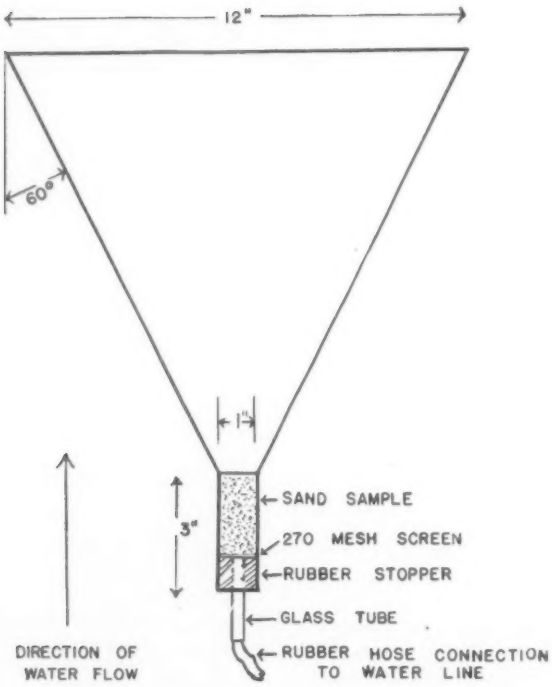

FIG. 1—FUNNEL FOR MAKING CLAY SEPARATION.

Mr. C. Mathiesen has pointed out that using two, 2-min. periods, and the balance one minute periods of settling, gives practically the same results as the standard method, down to and including the 270 sieve. It makes a great difference in the pan material. Of course, if anyone wanted to include pan with clay, it would be his privilege to do so.

The Cincinnati Milling Machine Co., Cincinnati, Ohio, uses a funnel, (Fig. 1) developed by W. A. Rengering, the sides of which have a 60° slope. Across the bottom is a 270 mesh sieve. Water flows up through the stem of the funnel and overflows at the top. The sample of sand, after being dispersed in the usual manner with sodium hydroxide, is then dumped into the funnel and the flow of water so adjusted that only A. F. A. clay is carried off at the top. What remains in the funnel is then dried and transferred to the sieves. It is said that by using two funnels it is possible to run as many as eight samples per day, depending on the clay content and grain size.

Another method in successful use consists in dispersing the sand sample in the usual manner. It is then transferred to a 1,000 cc. graduate, distilled water is added and the cylinder upended several times for one minute. The grains are then allowed to settle and, at the end of 5 min., the amount of material less than 20 microns in size can be deter-

mined with a pipette[2] or hydrometer.[3] The pipette method is used for sand testing at the Naval Research Laboratory in Washington.

Fineness Number—Some years ago the Committee recommended a method for calculating the average fineness of a sand and this is widely used, although some have objected to the inclusion of pan material in this calculation. The chief objection to the fineness number is that two sands of different grain distribution may have the same average fineness. Both the A. F. A. subcommittee on grading and fineness, and the Foundry Sand committee of the N. I. S. A. are now studying the method of expressing fineness with a view to improving it.

This, incidentally, leads to what should be included under the term "fines." Although some include everything below the 100 mesh, the Committee some time ago recommended that it should include those particles of sand which are retained on the 200, 270 sieves and pan. There seems, however, to be no adherence to this rule because it is applied differently in shops making castings from different types of metal, such as gray iron, steel, malleable and non-ferrous, and also varies with the type of casting being made, whether light, medium or heavy.

Character of Clay—Some have suggested that we should know more about the character of the A.F.A. clay, and accomplish this by separating it into its two main components. It includes all particles up to 20 microns in size, and is made up of fine silt grains (0.02-0.005 mm.) and true clay particles (0.005 mm. and under). The former do not have the bonding power of the latter. Therefore, we can understand that two sands of the same grain distribution, and the same amount of A.F.A. clay might show a difference in strength, depending on the proportions of fine silt and true clay particles which they contain.

It would not be a difficult matter to determine these separately with a pipette or hydrometer. With the former, it would require a reading at the end of 5 min. to get A.F.A. clays, and some time longer for determination of true clay.

Distribution Factor—Largely because the fineness number did not indicate the degree of distribution of the different-sized grains on the several sieves, and because two sands of the same average fineness might show a different distribution, the Committee was asked to develop a method for determining this feature. A large amount of time was spent by the Subcommittee on Fineness and Grading in an effort to do this. They finally developed and recommended a method which involved considerable calculation, but which has met with so much opposition that the Committee has voted to reject it, and is trying to find a simpler one.

It may be better to attempt to find a method which is extremely simple, even though it may not show a high degree of accuracy. It would

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[2] Jackson, C. E. and C. M. Saeger, Jr., *"Use of the Pipette Method in the Fineness Test of Molding Sand,"* National Bureau of Standards, RESEARCH PAPER 757, 1935.

[3] Wintermyer, A. M., E. A. Willis and R. C. Thoreen, PUBLIC ROADS, vol. 12, No. 8, Oct. 1931.

seem that just plotting the fineness curve might, at a glance, give one a sufficient idea of the distribution.

The Sand Research Committee has recommended a method for making a sieve test, for calculating the average fineness and for calculating distribution. It should be understood that these are simply recommended methods for accomplishing certain things and the foundryman is at liberty to use any or all of them just as he pleases. If he feels that none of them suits his purpose, he is under no obligation to employ them. If, in using the sieve test, he wants to combine pan and A.F.A. clay, or if he wants to lump together the percentage of the grains retained on three adjacent sieves, he is also at perfect liberty to do so.

Grading—The Committee also suggested a Grain Fineness classification[1]. It was not long before one group found fault with this, claiming that certain grain classes were too broad and should be subdivided. Since it will be recognized that any other groups might make the same request, it would seem that in those cases where the grain class is too broad, the consumer might better specify the percentage of grains on certain sieves. The same might apply to the clay class.

Green Deformation—It seems to be a question whether or not the property of green deformation is given as much attention by foundrymen as it deserves: indeed a rather wide difference of opinion is expressed by different ones regarding the importance of such a test.

Attention was called to this property in a paper by Dietert[4] in 1936, in which some of the practical bearings of the green deformation test are pointed out.

As said by some, the manner of using the sand may have a great deal of bearing on the value of the green deformation test. In view of the fact that some foundrymen have doubts regarding the value of this test, it may be well to give the opinions of several who use it extensively.

One writes, green deformation ". . . is directly related to the ability of sand to resist a tendency to crush under load. It is a property of the sand which encourages or prevents crushes in foundry practice. Crushes may be due to improper pattern equipment, improper manufacture of pattern itself or manipulation of operator in placing cope on drag. In latter case, if cope does not come down horizontally, or flask pins are loose, it is very apt to cause a crush unless sand is able to deform sufficiently."

Cope drops and broken edges of molds when drawing patterns may be due to sand being too brittle, even though having sufficient green compressive strength. Green deformation should show the trouble.

Another operator writes: "Deformation shows 'liveness' or 'deadness' of a facing. A sand mix with dead feel may test all right for green compression and moisture, and yet be unfit for foundry use. If mulled

[1] Ibid, p. 103.

[4] Dietert, H. W. and Dietert, R. A., *"Deformation and Resilience of Molding Sand,"* A.F.A. TRANSACTIONS, vol. 44, p. 139, 1936.

longer, it may gain life and deformation rise proportionately. If, on the other hand, the mixture is mulled too long, it may ball up in the mill and deformation rise too high; "hence deformation may serve as a check on the sand as well as the efficiency of the mill operator."

It is stated by one operator that, "Low deformation has caused us to experience the following: (1) Rough mold surface when pattern drawn from sand, (2) mold surface erodes easily when cleaning with compressed air, (3) mold hard to finish, making molders complain of poor quality facing, (4) after air drying, sand grains slough off leaving a very weak sand and causing dirty casting; and (5) mold has strong tendency to crush on closing."

"With deformation values high, the sand rams with difficulty and a low mold hardness is experienced in spots causing swells on the castings."

"If moisture is constant and compressive strength increases while green deformation decreases, it may be an indication that mill operator has added bond to get the proper feel."

As illustrative of the bearing of green deformation on the behavior of a sand, the following test data on the same sand obtained on two different days may be quoted.

	Moist.	*Green Comp. lb. per sq. in.*	*Green Shear lb. per sq. in.*	*Green Perm.*	*Mold Hard.*	*Deformation-in.*
1	4.1	8.1	2.5	150	76	0.015
2	4.2	7.3	2.4	150	72	0.030

Disregarding green deformation, No. 1 would seem to be superior, but if used would show excessive sloughing off, and washing during pouring. No. 1 castings would be dirty and No. 2 clean. It would seem as if the difference in green deformation is the cause.

Tensile Strength—It appears that this test is not used as often as the green compression test, although some foundries specify it. Others use both tensile strength and green compression in laboratory tests. Some foundrymen believe that it gives no information not given by the green compression test.

One opinion expressed is that in brittle sands, the tensile strength is relatively lower than green compression.

Some believe that the green tensile strength test is more important for checking trouble in plate or brass sands of 180 or greater average fineness. It is thought in this connection that the tensile strength of fine sands gives a more accurate indication of active clay content than does the compression strength, as the "fines" in the sand create more compression than tensile strength. Furthermore the tensile strength decreases more rapidly than the compression strength as the sand successively burns out.

TROUBLES CAUSED BY IMPROPER TECHNIQUE

a. Ramming— There is no more widely used step in clay testing than the preparation of the standard specimen by ramming, and the Foundry Sand Research Committee has made every effort to get this standardized. In the Handbook of testing[1] attention was called to the fact that *the character of the support has some influence on the test results*, and in the A.F.A. Transactions[2] a number of figures were given to emphasize this point. Nevertheless, it has been found that there is some laxity in this matter. For this reason, attention is again called to the fact that the rammer base *should rest on and be fastened to a firm non-yielding support*.

It is found, for example, that if the rammer base is bolted to a concrete base, a solid wood timber support or a thick heavy iron plate, the best results will be obtained. A yielding support means less intense ramming and the same sand will, under such conditions, show higher permeability and lower compression-strength figures.

b. Specimen Tubes—Care should be given to specimen tubes to see that the inner surface is kept perfectly smooth, otherwise variation in results of strength tests are likely to occur.

c. Clay Separation—The viscosity of water decreases with a rise in temperature. Consequently, particles of a given size may settle more rapidly in warmer water. Therefore, two clay determinations might not agree if made with water of different temperatures. This may account for some of the discrepancies that are sometimes noticed when comparing the results of two different operators.

TESTS UNDER INVESTIGATION

Sintering Test—Although the Committee several years ago suggested a sintering test and attempted to recommend a method for making the same, there has been a lack of uniformity in interpreting the results obtained, and a new Subcommittee is now at work attempting to improve the technique of the test.

Core Hardness—The Subcommittee appointed to recommend a method for determining this property, suggests the use of a hard metal plow which protrudes through a slot in a plate. This plate is drawn across the surface of the core, and the projecting plow causes a scratch whose depth depends on the hardness of the core. The plow is spring loaded, and can be connected with a dial indicator which shows the depth of penetration of the plow.

Durability and Flowability are two properties for which no test has yet been recommended by the Committee. Both represent important problems not yet satisfactorily solved. Subcommittees have been appointed to study them.

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[1] Ibid, p. 118.

[2] *Report of Committee on Sand Tests*, TRANSACTIONS, American Foundrymen's Association, vol. 35, p. 182 (1927).

Definitions—With the development of high-temperature tests, it has become necessary to formulate terms to be used in referring to the properties and behavior of sands when heated. Certain terms now in the glossary of the Handbook of Testing have also been clarified. The Subcommittee appointed for this purpose has presented a report which is shown in Appendix 1.

Tests of Steel Sands at High Temperatures—Following last year's Convention there was issued a progress report by Subcommittee 6b7, outlining the work that had been done on the mixtures specified by it. Since the publication of this report some further work was done on cereal-bentonite mixture, but this was not completed because of the resignation of the man employed to do this work. It will be completed as soon as a new man for the work can be found. In the meantime, however, G. W. Ehrhart, graduate student in Mechanical Engineering, Cornell University, Ithaca, N. Y., has been carrying on some interesting tests on the expansion at high temperatures of the mixtures previously tested. The results of this work will appear later.

The Subcommittee has approved a program for further work in which more effort will be made to determine the effect of individual constituents of steel-sand mixtures, an important matter regarding which we still need reliable information.

Specifications—This is a matter which does not really concern the Foundry Sand Research Committee, for, as previously mentioned, it is the function of the committee to recommend tests for determining the properties of sand. However, brief reference may be made to specifications used.

Study of the purchase specifications issued by several dozen foundries show no uniformity as to properties mentioned or tolerances allowed.

In the case of silica sands, some specify the entire sieve test and in some cases note a tolerance permitted on each sieve. Others may specify an allowable maximum on the coarser sieves, and an allowable maximum through 100, and perhaps a maximum retained on three or four adjacent sieves. This last is a condition which is probably easiest for the producer to meet. A few consumers specify the shape of sand grains. Not a few note fineness number for any type of sand.

When it comes to naturally-bonded sands, we find permeability, green compression, shear strength, and clay content mentioned in specifications, but there is no uniformity of demand nor any uniformity of allowed tolerance where this or any other property is mentioned.

Future Problems—There is still much to be done in the study of molding sands. We have recognized certain properties and we have set up methods whereby most of these properties can be tested. Others are in preparation. There is still much work to do in determining the causes of the differences in behavior of different sands and mixtures. It is also possible that there is a relationship between certain properties

not hitherto suspected. To get at the solution of these problems calls for much painstaking work, involving the study of numerous mixtures under varying conditions. Work of this sort undertaken to determine the effect of different constituents and different conditions, should be so carried out that we have at first to deal with only one variable, and work from simple to more complex conditions.

It seems to the writer not unreasonable to hope that such investigations may lead to the development of simpler mixtures than some of those now used. The use of synthetic sands affords a good chance for composition control; furthermore, testing synthetic mixtures should help us to better understand variations in the behavior of naturally-bonded sands.

Cast Iron Cylinder Bores — Observations on Microstructure, Composition, Hardness and Wear

By E. K. Smith*, Detroit, Mich.

Abstract

In this paper, the author records his findings in a study of the structure and properties of cast irons in the bores of cylinder blocks at the point of greatest wear. These tests were conducted to support his contention that microscopic examination of cylinder bore structures offers the foundry laboratory a valuable means of controlling structure and would supplement and confirm chill and Brinell hardness tests and analyses. In his study, the author examined many specimens from cylinder bores at a point about ½-in. from the top of the bore, and in this paper presents typical examples of his findings. He gives analyses and hardness numbers and comments on the reasons for either excellent, fair or poor wear experienced with the various types of microstructures found. From his data, he found, from examination of specimens from five different plants, that there appeared to be a relation between the amount of ferrite present in the structure and wear, the more ferrite present the greater the wear, provided normal, thin flakes of graphite were present. In the latter part of the paper, the author comments on some special cases involving such defects as porous bores, excessive wear and ferritic rims in cylinder bores, and gives a review of the literature on the causes and prevention of cylinder bore wear. As a result of his study, the author concludes that the best cylinder bore structure, at position of maximum wear, should consist of an entirely pearlitic matrix with long, thin flakes of normal graphite, no ferrite, and sufficient small particles of iron-chromium carbide to increase resistance to wear.

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Note: This paper was presented at a Gray Iron Session of the 44th A.F.A. Convention, May 10, 1940, Chicago; Ill.

1. Wear tests on motor blocks have been carried on ever since the early days when a few thousand miles marked the maximum service for the motor. More recently, accelerated laboratory tests for cylinder bore and piston ring wear have furnished valuable information. Theories have been advanced for or against certain types of cast iron structure, but the subject is still controversial.

2. In the study of cylinder bore wear, service tests are of course most accurate, provided the variables can be controlled. However, service tests are a long drawn out process. Laboratory tests are necessarily expensive. However, the microscopic examination of cast iron is both rapid and inexpensive. The author feels that the rapid routine microscopic examination of cylinder bore structure would offer the foundry laboratory a valuable means of controlling structure, and would supplement and confirm the present chill tests, Brinell hardness number, and analyses.

3. Therefore, this study of the microstructure of both new motor blocks and of those which have definite mileage and measured wear, was undertaken. It was thought that from such a study, some light may be thrown on the following problems:

(1) What is the actual structure of the present-day cylinder bores at the point of maximum wear?

(2) How does variation in structure actually affect wear?

(3) What is the most desirable structure for cylinder bores, having in mind such major considerations as machinability and cost, as well as wear?

(4) How can such structure be obtained practically?

4. Admitted that other variables may be more important than the microstructure, that with perfect lubrication there is practically no wear, and that in the modern passenger car under present conditions, the wear has been so controlled that extremely long mileage is obtainable with ordinary usage; nevertheless, the cylinders are made of cast iron, and its structure must have an important bearing on wear.

PROCEDURE

5. To get a bird's-eye view of the microstructure of the cast iron cylinders being produced today, ten motor block sections were

obtained from eight different makes of motor cars. Analyses and photomicrographs were made of these, and some which might be of interest are given in the section "Examples of Microstructure." Although it is well-known that special types of liners are being used, either subjected to special treatment, or made of a different type of material, it is considered that such special applications do not come within the scope of this discussion. The bores studied, therefore, were taken from conventional cast iron motor blocks.

Location of Test Specimens

6. In order that there might be a reasonable degree of uniformity, the sample for microscopic examination was taken, wherever possible, on the side of either No. 2, No. 5 or No. 7 cylinder at approximately the position of greatest wear from the top piston ring. Generally speaking, this area was about ½-in. from the top of the bore. In every case, the photomicrograph was taken on a cross section showing the actual structure at the point of maximum wear.

7. After analyses and microstructures were taken on the above mentioned bores for preliminary information, bores with measured mileage and wear were supplied through the kind cooperation of a number of the motor plants. Analyses and photomicrographs were also made of these irons and are illustrated in the section "Microstructure of Wear Test Cylinders."

Effect of Composition on Structure

8. Briefly, the structural constituents of cast iron as shown in the microscope are as follows:

(1) *Ferrite:* Pure iron. Very soft; resembles wrought iron in appearance and physical properties. Appears in the form of white grains.

(2) *Graphite:* Carbon separates out in the form of graphite, generally in black flakes. The size, shape and distribution of the graphite flakes have a strong effect on physical properties and wear of cast iron.

(3) *Pearlite:* This constituent is generally considered the most desirable in modern cast iron. It is composed of alternate layers of carbide of iron and ferrite. It is strong, ductile, machinable and wear resistant.

(4) *Iron Carbides:* Carbides appear in the form of small very white particles of irregular shape. The carbide is intensely hard. Carbides promote resistance to wear, but in excessive amounts, decrease machinability.

(5) *Iron Phosphide:* Practically all motor irons show patches of white material dotted by a softer constituent. These are the iron phosphide. They are hard and brittle, and their net effect on iron is controversial.

(6) *Manganese Sulphide:* Manganese combines with sulphur, offsetting the detrimental effects of the latter. Manganese sulphide is found in the shape of small rectangular particles, usually of light gray color. They have little effect on the iron.

9. Without going into detail, it may be pertinent to sum up the effect of the various elements of cast iron on its microstructure when other variables, such as section size, cooling rate, etc., are constant. Silicon and carbon soften the iron, causing formation of graphite, and if present in large enough quantities, of ferrite. Manganese in the ordinary range from, say, 0.55 to 0.90 per cent, has little effect on microstructure, but aids considerably in controlling the effect of sulphur. If manganese and sulphur are balanced, neither has much effect on the iron. High sulphur with low manganese causes brittleness, and intense hardness. Phosphorus is seen in microstructure in the shape of hard islands of iron phosphide. Where phosphorus is excessively high, the iron tends to be brittle. However, the hard phosphides retard wear. Nickel in general acts as a graphitizer, tending to graphitize light sections, thus promoting machinability. Chromium forms stable carbides, thus tending to prevent the formation of coarse graphite and ferrite. It hardens the iron. Molybdenum promotes fine graphite and strength.

EXAMPLES OF MICROSTRUCTURE

10. Three photomicrographs were made of each spot. The first, at 100 diameters unetched, shows the graphite formation. The second, at 100 diameters etched with nital, shows the general structural components of the iron; for instance, ferrite, pearlite, graphite and carbides. The third, at 1,000 diameters etched with nital, shows the detailed structure, important in the study of wear.

11. Fig. 1-Top illustrates a normal structure of graphite, while Figs. 1-Bottom and 2 show a highly pearlitic structure. The Brinell hardness number of this iron was 180. Analysis of the iron is given in Table 1.

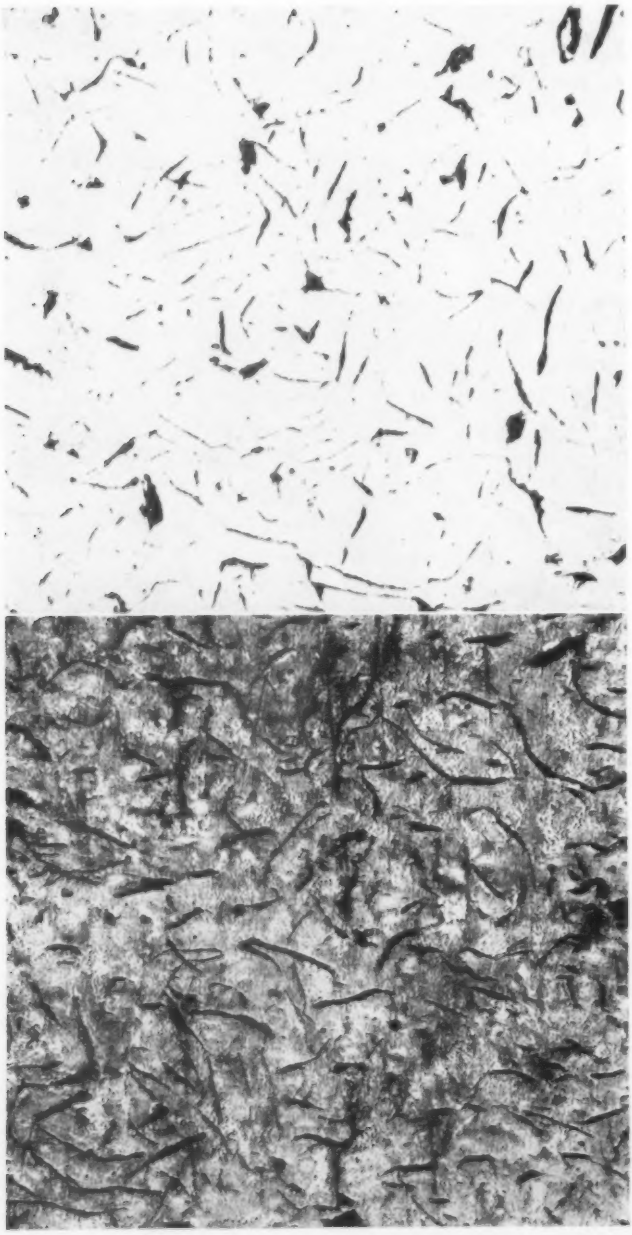

FIG. 1—NORMAL STRUCTURE OF AN UNALLOYED IRON. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

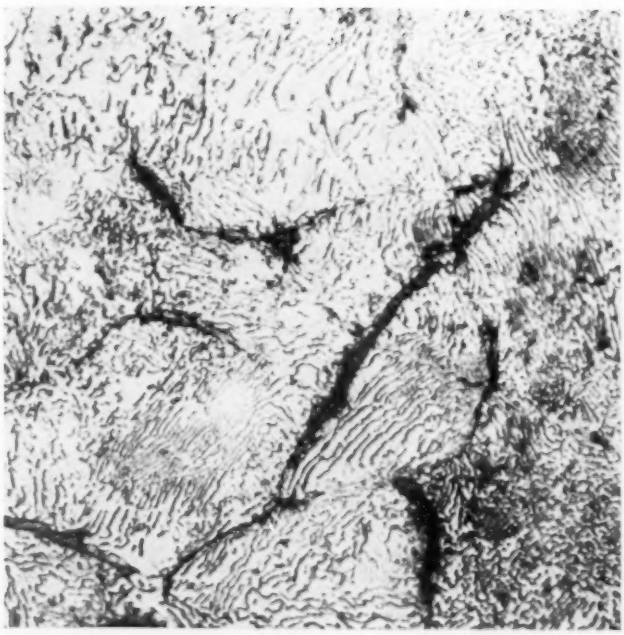

FIG. 2—SAME IRON AS FIG. 1, ETCHED WITH NITAL, 1000X.

Table 1

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 1 AND 2

Element	*Per Cent*
Silicon	2.28
Manganese	0.67
Total Carbon	3.35
Graphite Carbon	2.86
Combined Carbon	0.49
Sulphur	0.084
Phosphorus	0.165
Chromium	0.03
Nickel	0.12
Molybdenum	0.02

Brinell Hardness Number—180.

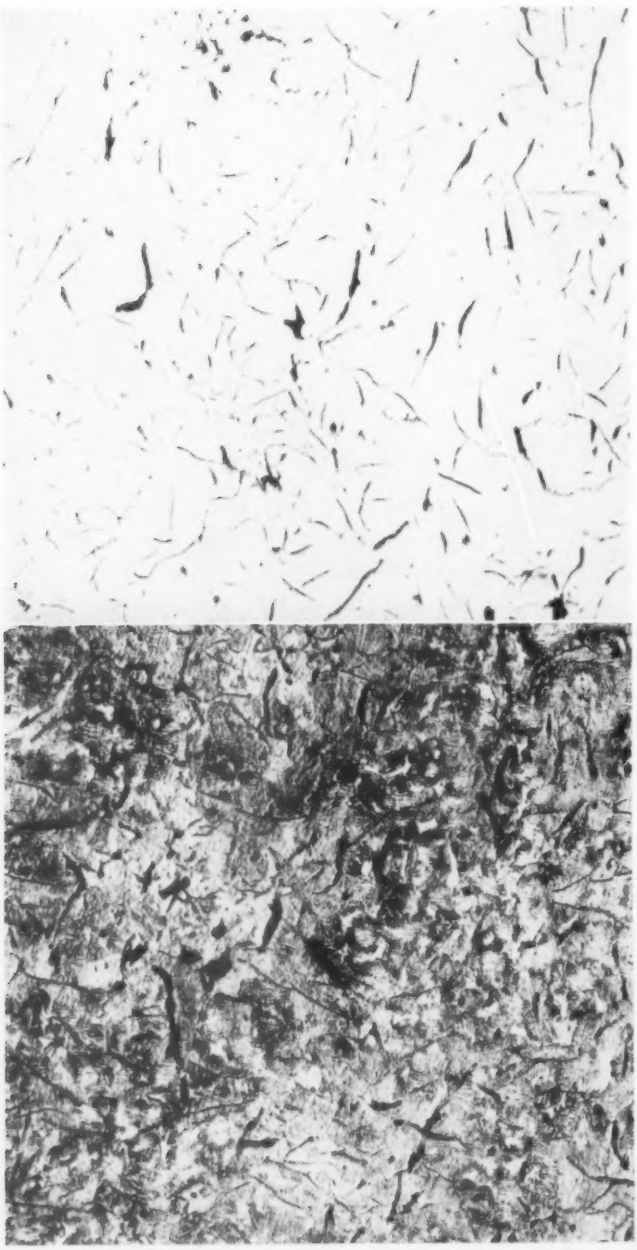

FIG. 8—NORMAL STRUCTURE OF AN ALLOYED IRON. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

12. It will be noted that Figs. 3 and 4 indicate a pearlitic structure with a very small amount of ferrite. Nickel was 1.45 per cent, and chromium was 0.61 per cent. Brinell hardness was 197. Analysis of the iron is given in Table 2.

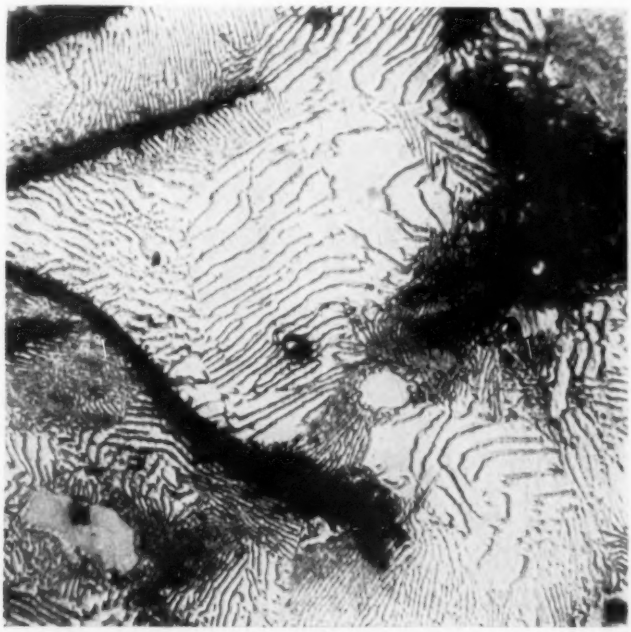

FIG. 4—SAME IRON AS FIG. 3, ETCHED IN NITAL, 1000X.

Table 2

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 3 AND 4

Element	*Per Cent*
Silicon	2.14
Manganese	0.56
Total Carbon	3.32
Graphite Carbon	2.75
Combined Carbon	0.57
Sulphur	0.113
Phosphorus	0.195
Chromium	0.61
Nickel	1.45
Molybdenum	0.01

Brinell Hardness Number—197.

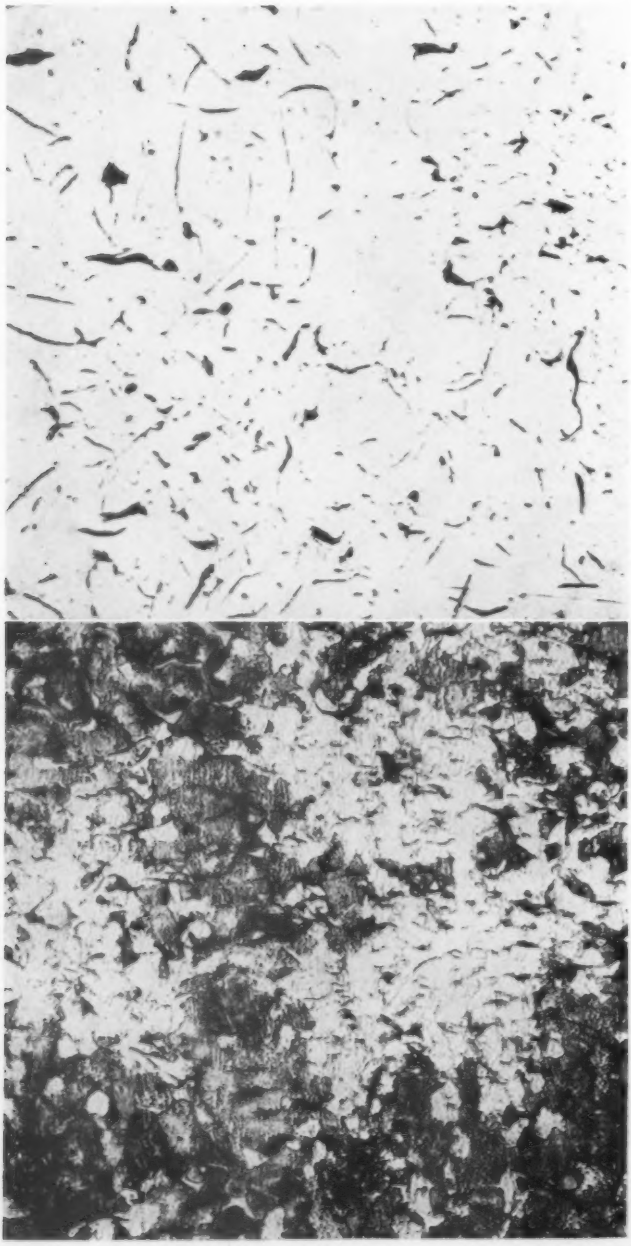

FIG. 5—IRON CAUSING SOFT BORES IN CYLINDERS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

13. The Brinell hardness of the sample, from which Figs. 5 and 6 were obtained, was only 146. The softness of the iron is verified in the microstructure, which shows the familiar rosette type of graphite with ferrite in Fig. 5. Fig. 6 illustrates the grains of soft ferrite in a pearlitic background, as well as several inclusions of manganese sulphide. The analysis, shown in Table 3, is a conventional unalloyed cast iron. This is a good example of an extremely soft iron such as is rarely found.

FIG. 6—SAME IRON AS FIG. 5, ETCHED WITH NITAL, 1000X.

Table 3

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 5 AND 6

Element	*Per Cent*
Silicon	2.05
Manganese	0.57
Total Carbon	3.20
Graphite Carbon	2.84
Combined Carbon	0.36
Sulphur	0.123
Phosphorus	0.201
Chromium	0.14
Nickel	0.10
Molybdenum	0.01

Brinell Hardness Number—146.

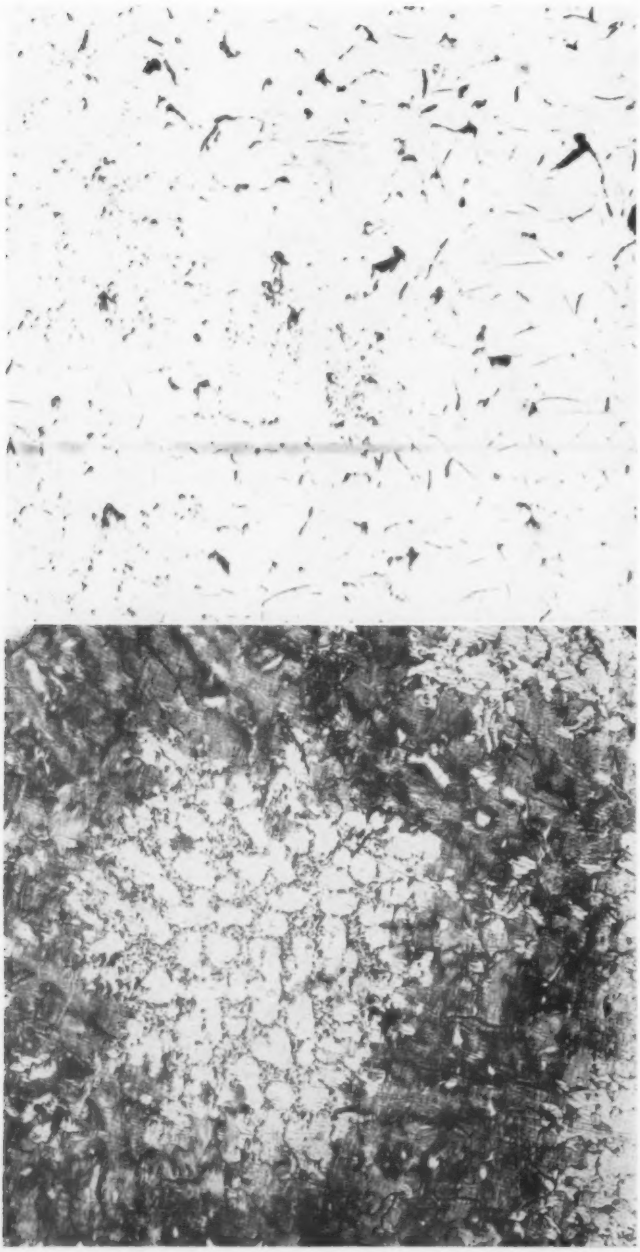

FIG. 7—AN IRON SHOWING POOR STRUCTURE DUE TO HIGH SILICON CONTENT. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

14. Figure 7-Top illustrates typical patches of fine graphite and ferrite, usually in dendritic form. While the Brinell hardness of this sample is satisfactory (187), the cause for the poor structure is seen in a very high silicon (Table 4). Figs. 7-Bottom and 8 show a high proportion of ferrite.

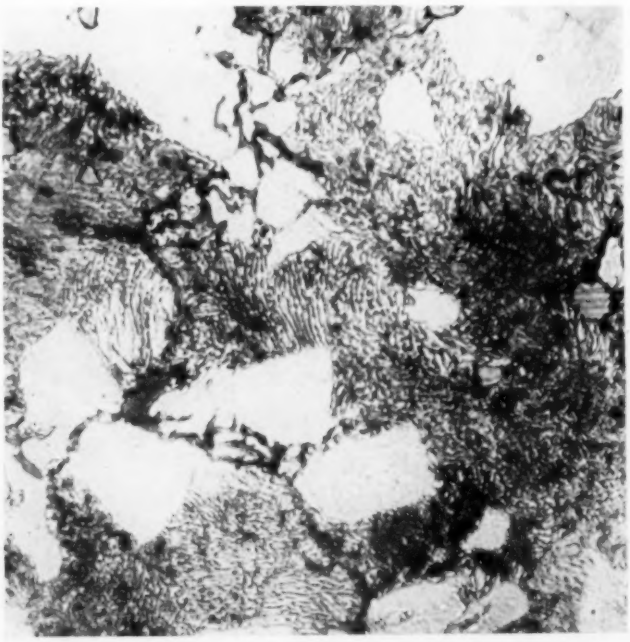

FIG. 8—SAME IRON AS FIG. 7, ETCHED WITH NITAL, 1000X.

Table 4

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 7 AND 8

Element	*Per Cent*
Silicon	2.57
Manganese	0.80
Total Carbon	2.94
Graphite Carbon	2.57
Combined Carbon	0.37
Sulphur	0.114
Phosphorus	0.141
Chromium	0.19
Nickel	0.20
Molybdenum	0.01

Brinell Hardness Number—187.

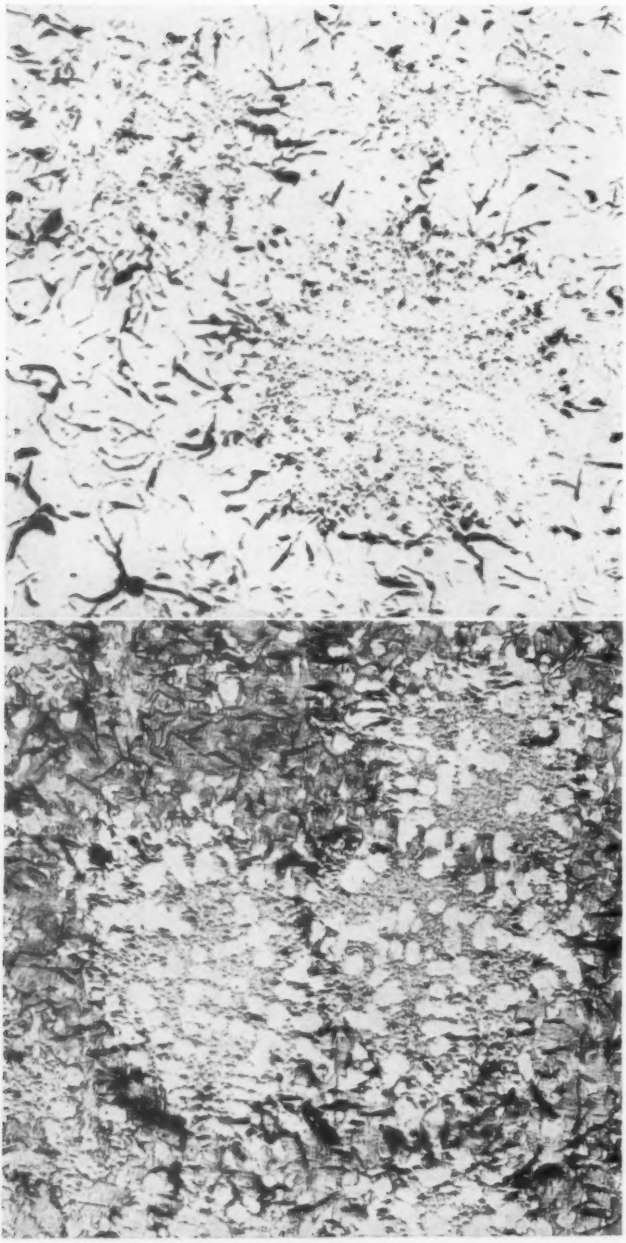

FIG. 9—AN IRON CAUSING SOFT BORES IN CYLINDERS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

15. Figs. 9 and 10 show an extreme case of ferrite-fine graphite structure, accompanied by low Brinell hardness (152).

MICROSTRUCTURE OF WEAR TEST CYLINDERS

16. After examining a number of cylinder bores with and without wear data, it became apparent that each type of motor block has general characteristics governing its wear. It appeared

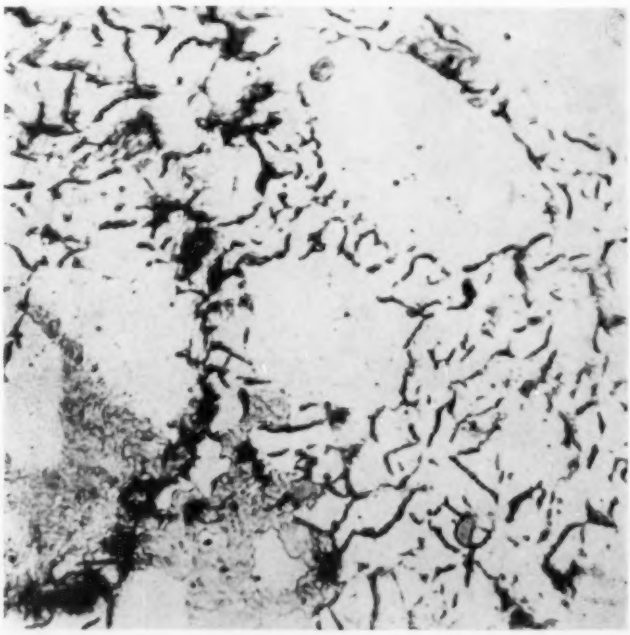

FIG. 10—SAME IRON AS FIG. 9, ETCHED WITH NITAL, 1000X.

Table 5

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 9 AND 10

Element	*Per Cent*
Silicon	2.37
Manganese	0.76
Total Carbon	3.21
Graphite Carbon	2.88
Combined Carbon	0.33
Sulphur	0.084
Phosphorus	0.158
Chromium	0.02
Nickel	0.15
Molybdenum	0.01

Brinell Hardness Number—152.

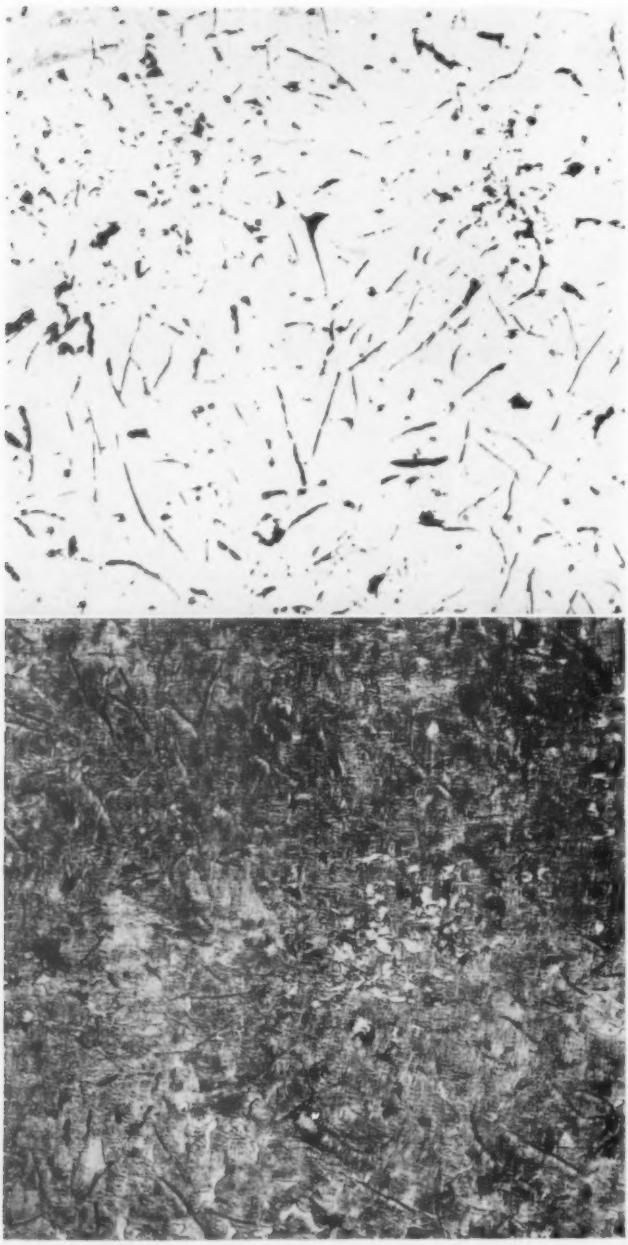

FIG. 11—AN IRON WITH EXCELLENT WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

that the same general relation held between the microstructure and the wear of the different types of motor block, but that the rates of wear are influenced in each type of motor block by certain more or less fixed characteristics, such as design, lubrication, analysis of iron, etc. Therefore, the wear data from each plant were examined as a unit as shown below, and the results of all were combined into one graph. For the sake of uniformity, wear was calculated to

FIG. 12—SAME IRON AS FIG. 11, ETCHED WITH NITAL, 1000X.

Table 6

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 11 AND 12

Element	*Per Cent*
Silicon	2.00
Manganese	0.87
Total Carbon	3.32
Graphite Carbon	2.73
Combined Carbon	0.59
Sulphur	0.139
Phosphorus	0.248
Chromium	0.02
Nickel	0.12
Molybdenum	0.01

Brinell Hardness Number—176.

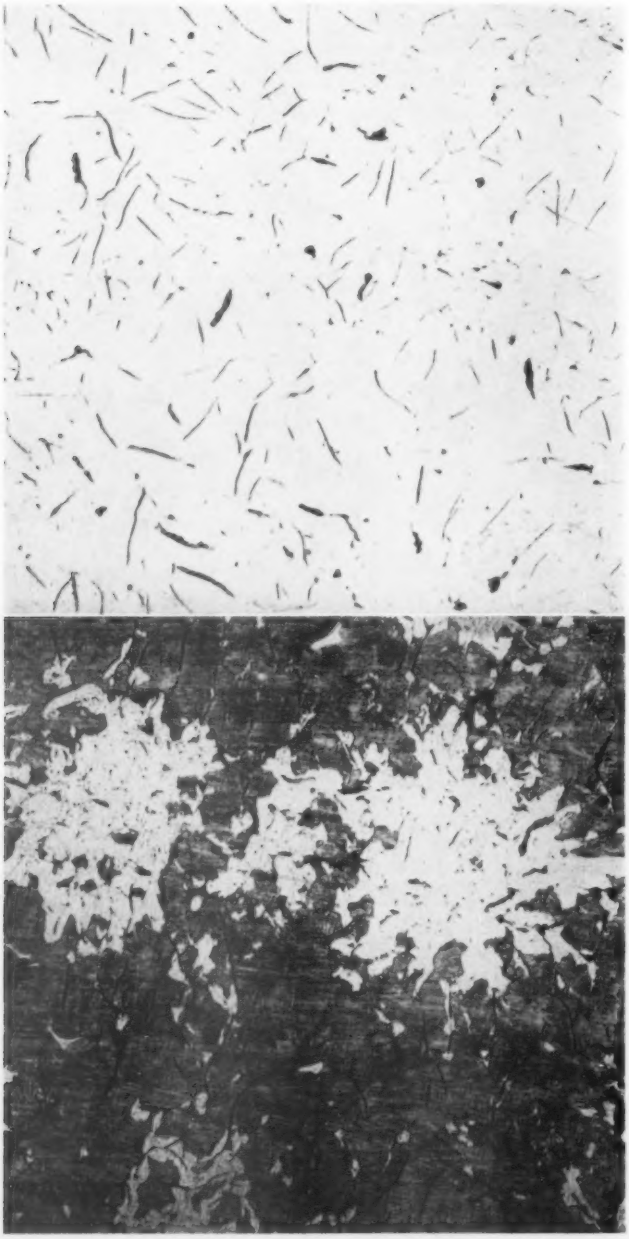

FIG. 13—AN IRON WITH FAIR WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

inches increased cylinder bore diameter per 10,000 miles service. The mileage varied from 25,000 to 55,000 miles.

Plant No. 1

17. In this case, cylinders were purposely produced with different types of microstructure, and these were subjected to careful accelerated wear test. Briefly, this consisted in running the

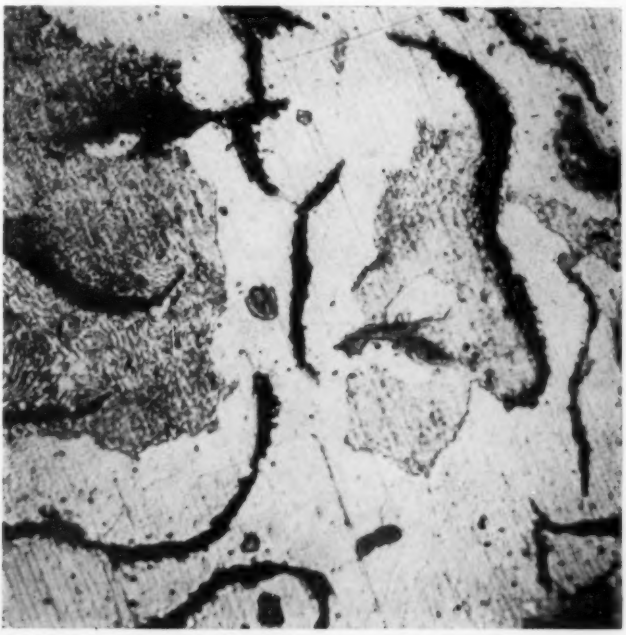

FIG. 14—SAME IRON AS FIG. 13, ETCHED WITH NITAL, 1000X.

Table 7

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 13 AND 14

Element	*Per Cent*
Silicon	1.83
Manganese	0.78
Total Carbon	3.39
Graphite Carbon	2.87
Combined Carbon	0.52
Sulphur	0.103
Phosphorus	0.137
Chromium	0.02
Nickel	0.07
Molybdenum	0.03

Brinell Hardness Number—183.

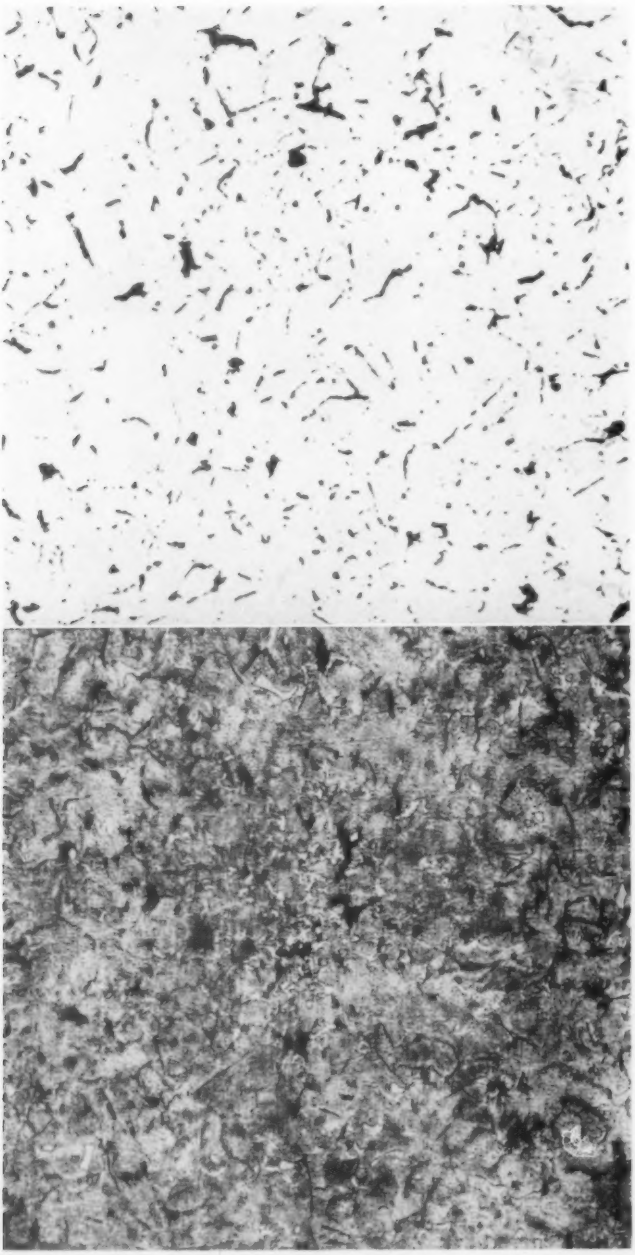

FIG. 15—AN IRON WITH EXCELLENT WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

engine from the start at 4,000 r.p.m. at full load, and continuing for two hours, so that both the rings and bores were operated under extreme "run-in" conditions, with probable boundary lubrication. It has been found that this test gives results comparable to those in actual service.

18. Fig. 11-Top illustrates in general, normal graphite, while Figs. 11-Bottom and 12 show an almost entirely pearlitic structure

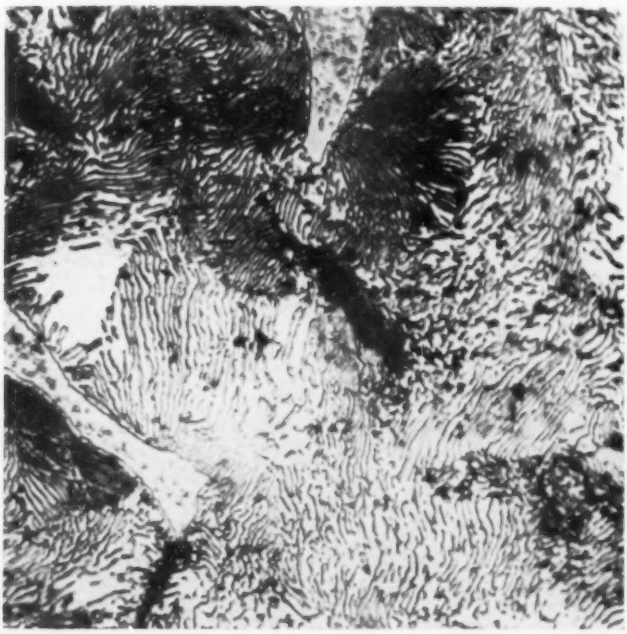

FIG. 16—SAME IRON AS FIG. 15, ETCHED WITH NITAL, 1000X.

Table 8

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 15 AND 16

Element	*Per Cent*
Silicon	2.18
Manganese	0.71
Total Carbon	3.33
Graphite Carbon	2.84
Combined Carbon	0.49
Sulphur	0.115
Phosphorus	0.248
Chromium	0.03
Nickel	0.26
Molybdenum	0.01

Brinell Hardness Number—196.

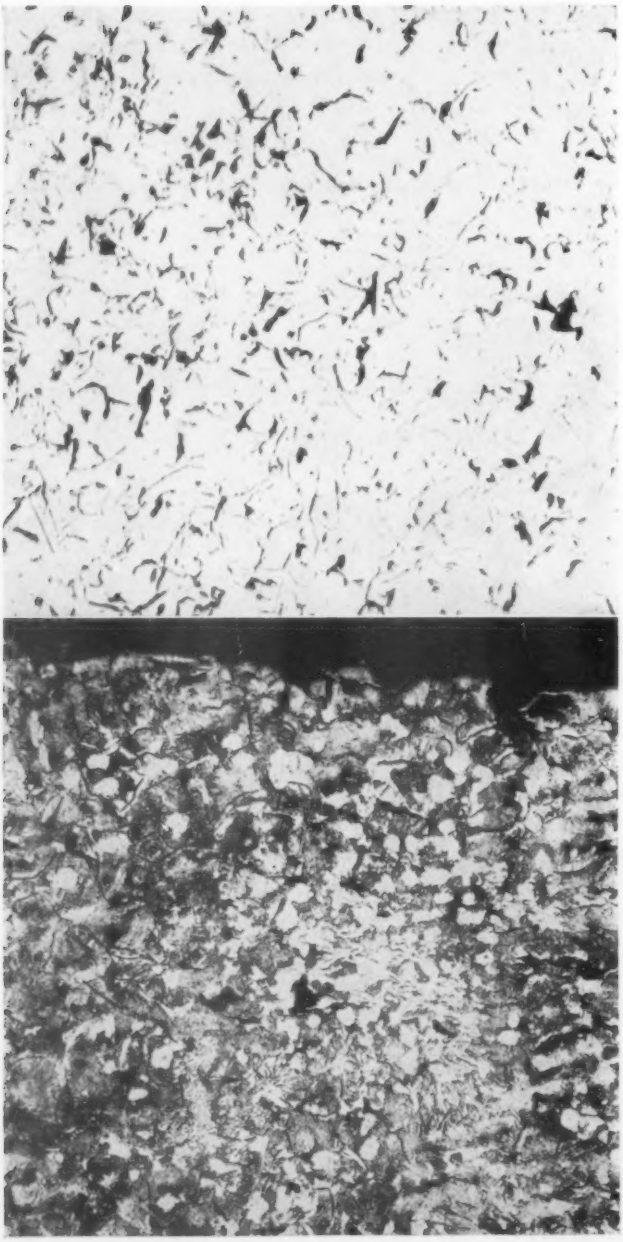

FIG. 17—AN IRON WITH FAIR WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

with a few small patches of ferrite. The wear on this sample was stated to be approximately half of that on the following sample tested under identical conditions.

19. The graphite structure in Fig. 13-Top is almost identical with that in Fig. 11-Top, but Figs. 13-Bottom and 14 show extremely large patches of ferrite. The wear on this sample was double that of the preceding one.

FIG. 18—SAME IRON AS FIG. 17, ETCHED WITH NITAL, 1000X.

Table 9

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 17 AND 18

Element	*Per Cent*
Silicon	2.52
Manganese	0.76
Total Carbon	3.34
Graphite Carbon	3.00
Combined Carbon	0.34
Sulphur	0.103
Phosphorus	0.298
Chromium	0.02
Nickel	0.06
Molybdenum	0.01

Brinell Hardness Number—169.

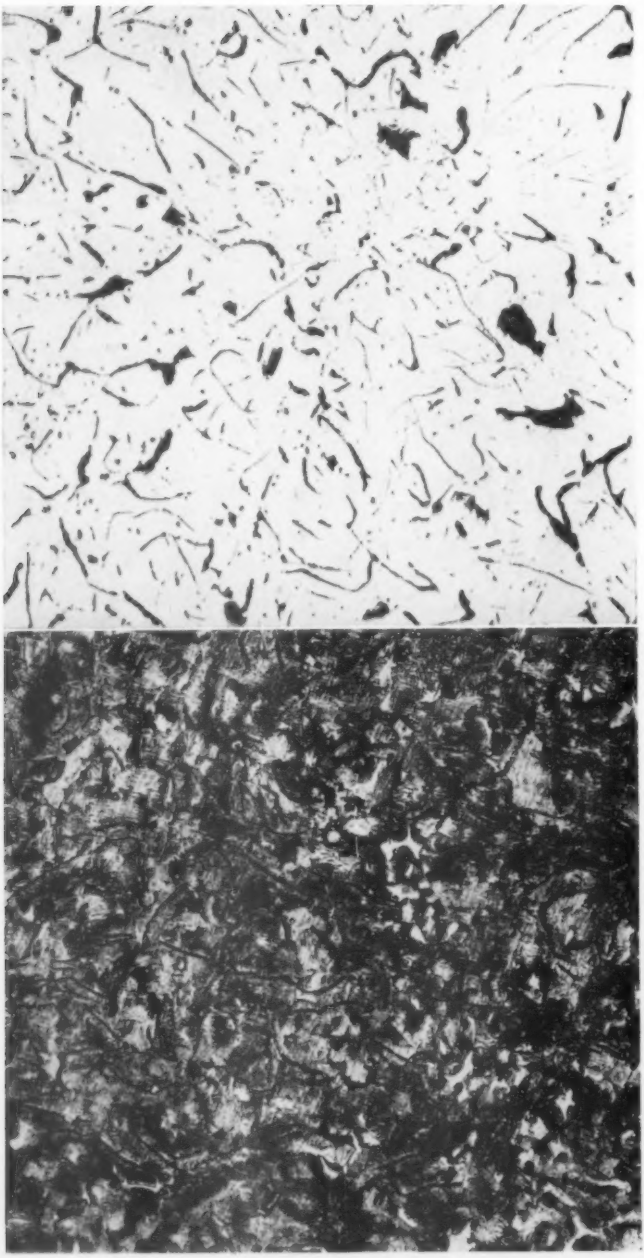

FIG. 19—AN IRON WITH EXCELLENT WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED 100X. BOTTOM—ETCHED WITH NITAL, 100X.

Plant No. 2

20. In this case, a number of cylinders were measured before going into service, and again after being dismantled. Mileage was observed. While a number of photomicrographs were made on all of these blocks, the two typical bores shown in Figs. 15, 16, 17 and 18 illustrate the structure.

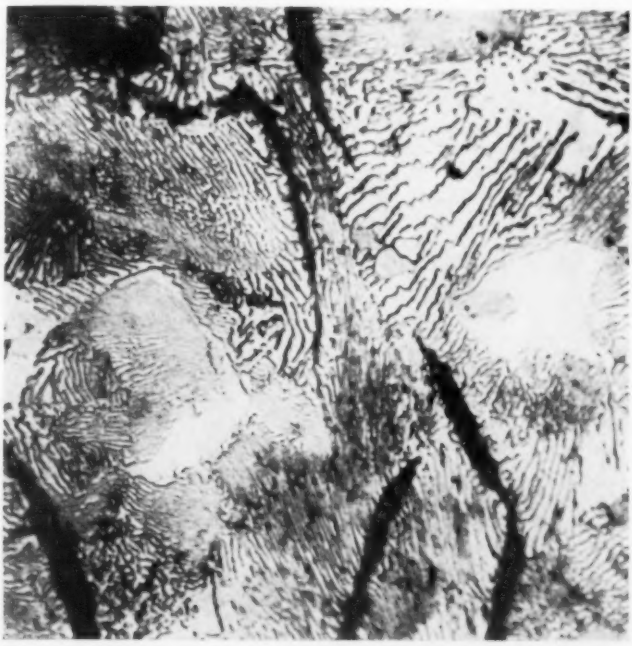

FIG. 20—SAME IRON AS FIG. 19, ETCHED WITH NITAL, 1000X.

Table 10

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 19 AND 20

Element	*Per Cent*
Silicon	2.42
Manganese	0.59
Total Carbon	3.38
Graphite Carbon	2.79
Combined Carbon	0.59
Sulphur	0.142
Phosphorus	0.203
Chromium	0.35
Nickel	0.25
Molybdenum	0.02

Brinell Hardness Number—183.

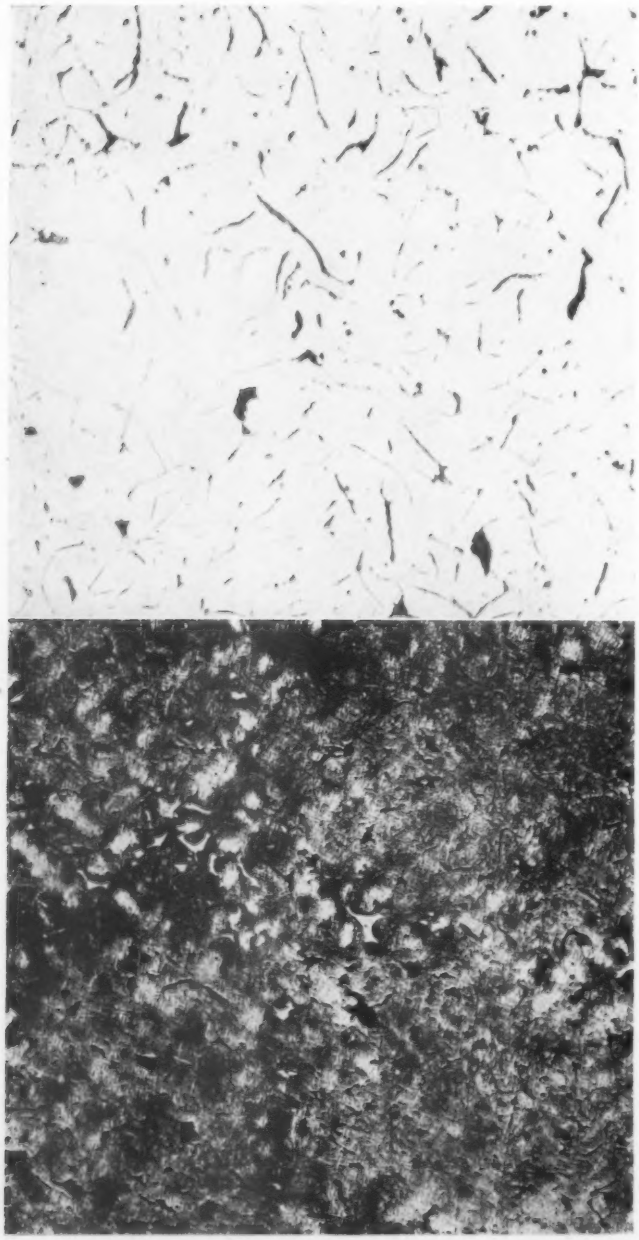

FIG. 21—AN IRON WITH EXCELLENT WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

21. Fig. 15-Top shows normal graphite, and Fig. 15-Bottom illustrates an almost entirely pearlitic structure containing very small amounts of ferrite. The wear on this sample was 0.001941-in. per 10,000 miles.

22. Fig. 17-Top and Bottom shows ferrite-fine graphite in the structure. The ferrite is more or less evenly dispersed throughout

FIG. 22—SAME IRON AS FIG. 21, ETCHED WITH NITAL, 1000X.

Table 11

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 21 AND 22

Element	*Per Cent*
Silicon	2.39
Manganese	0.56
Total Carbon	3.48
Graphite Carbon	2.79
Combined Carbon	0.69
Sulphur	0.153
Phosphorus	0.188
Chromium	0.36
Nickel	0.21
Molybdenum	0.02

Brinell Hardness Number—183.

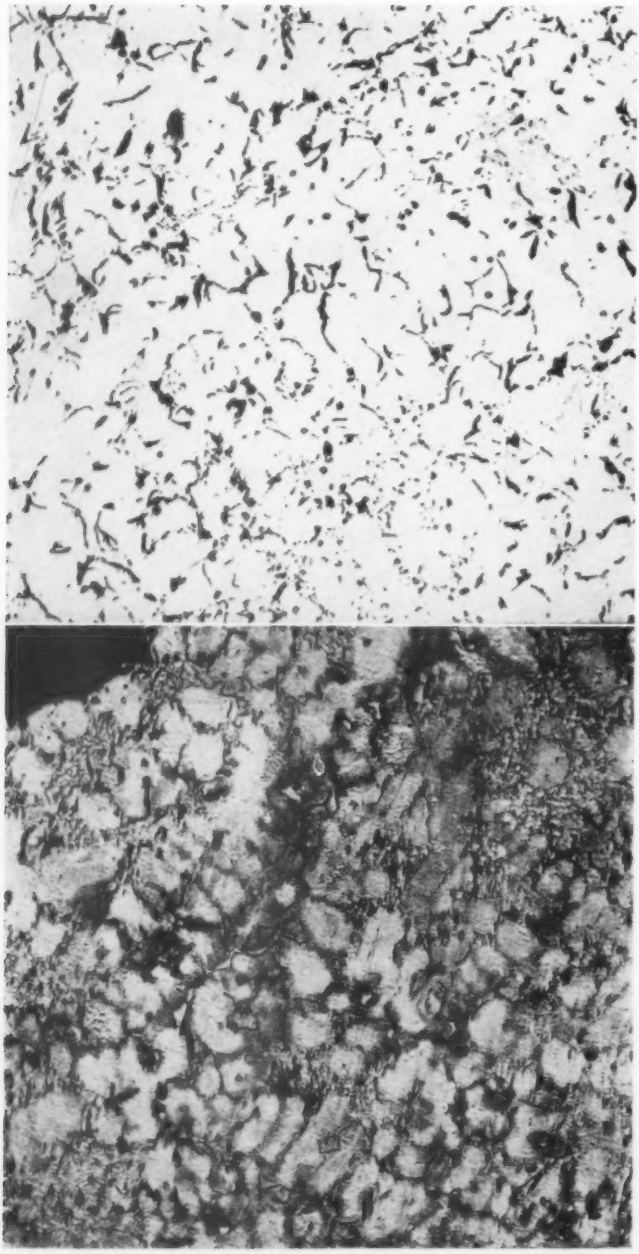

FIG. 23—AN IRON WITH FAIR WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

the field, which is rather unusual. It will be noted that the Brinell hardness on this bore was 169 as compared to 196 on the preceding bore from the same plant. Wear was 0.004026-in. per 10,000 miles. Silicon was too high.

Plant No. 3

23. Three different blocks were examined, each having had 40,000 miles of service. Two of the blocks show entirely different

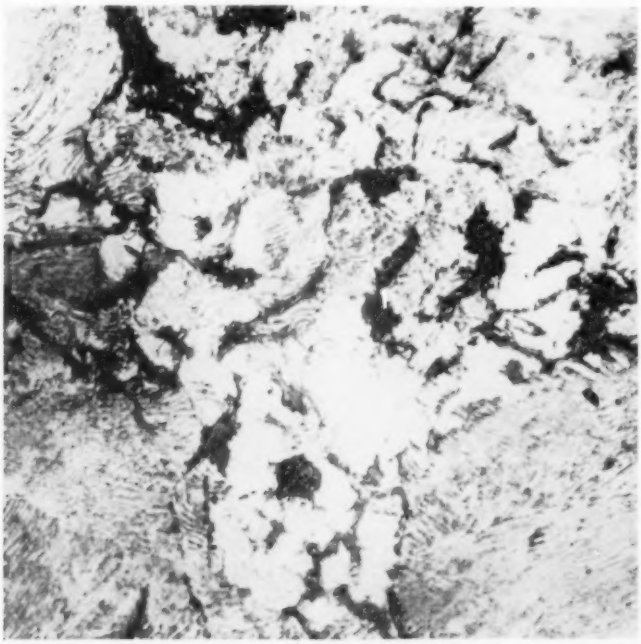

FIG. 24—SAME IRON AS FIG. 23, ETCHED WITH NITAL, 1000X.

Table 12

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 23 AND 24

Element	*Per Cent*
Silicon	2.15
Manganese	0.49
Total Carbon	3.28
Graphite Carbon	2.65
Combined Carbon	0.63
Sulphur	0.116
Phosphorus	0.121
Chromium	0.32
Nickel	0.13
Molybdenum	0.05

Brinell Hardness Number—183.

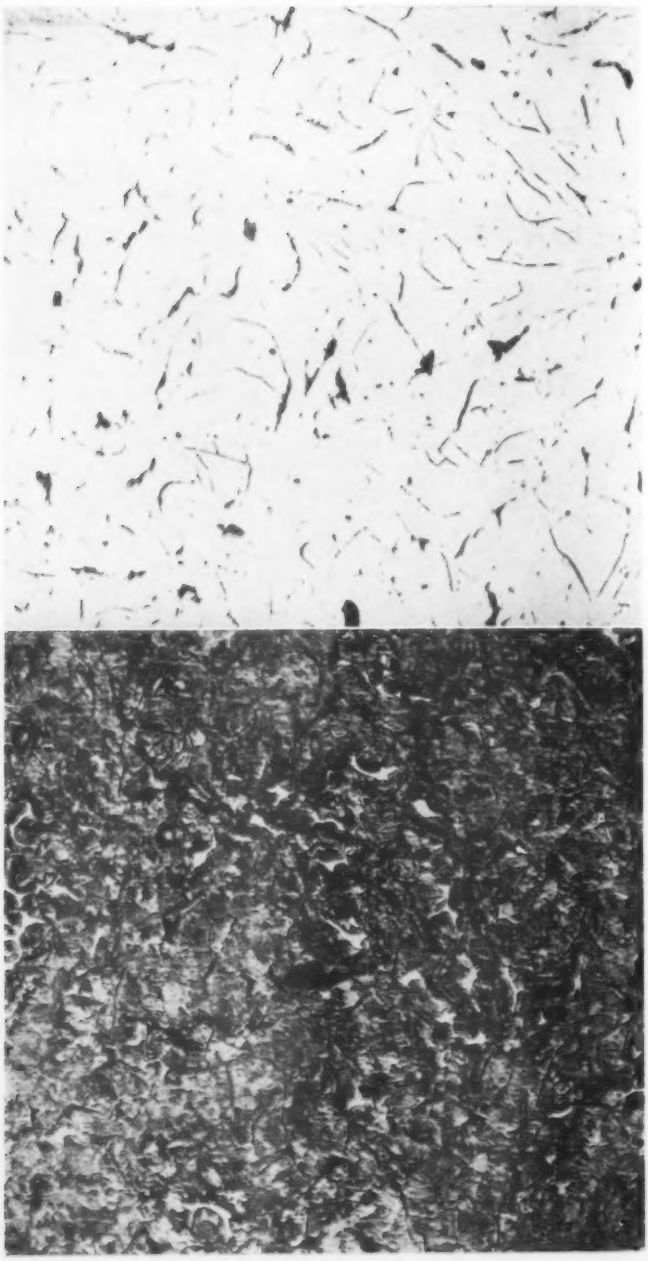

FIG. 25—AN IRON WITH EXCELLENT WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

microstructure from the third, and the wear tests verified this.

24. Fig. 19-Top shows normal, rather coarse graphite, and Fig. 19-Bottom shows practically no ferrite. Fig. 20 illustrates an almost entirely pearlitic structure. Wear was 0.000664-in. per 10,000 miles.

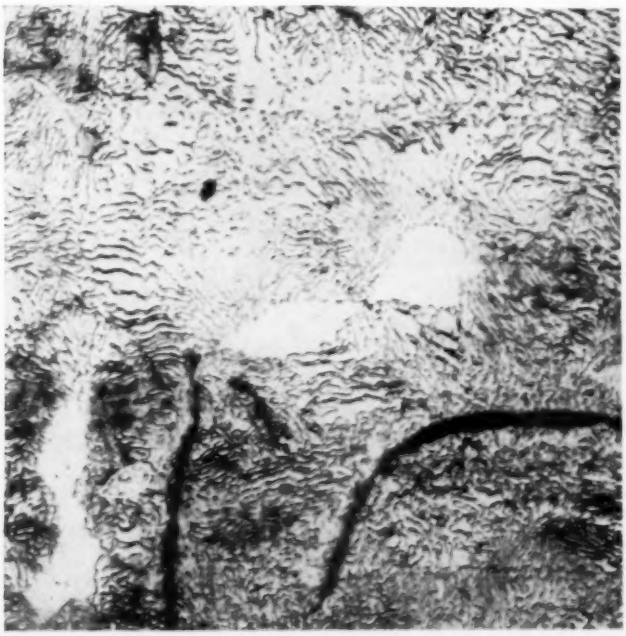

FIG. 26—SAME IRON AS FIG. 25, ETCHED WITH NITAL, 1000X.

Table 13

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 25 AND 26

Element	*Per Cent*
Silicon	1.76
Manganese	0.74
Total Carbon	3.28
Graphite Carbon	2.68
Combined Carbon	0.60
Sulphur	0.124
Phosphorus	0.200
Chromium	0.26
Nickel	0.21
Molybdenum	0.02

Brinell Hardness Number—187.

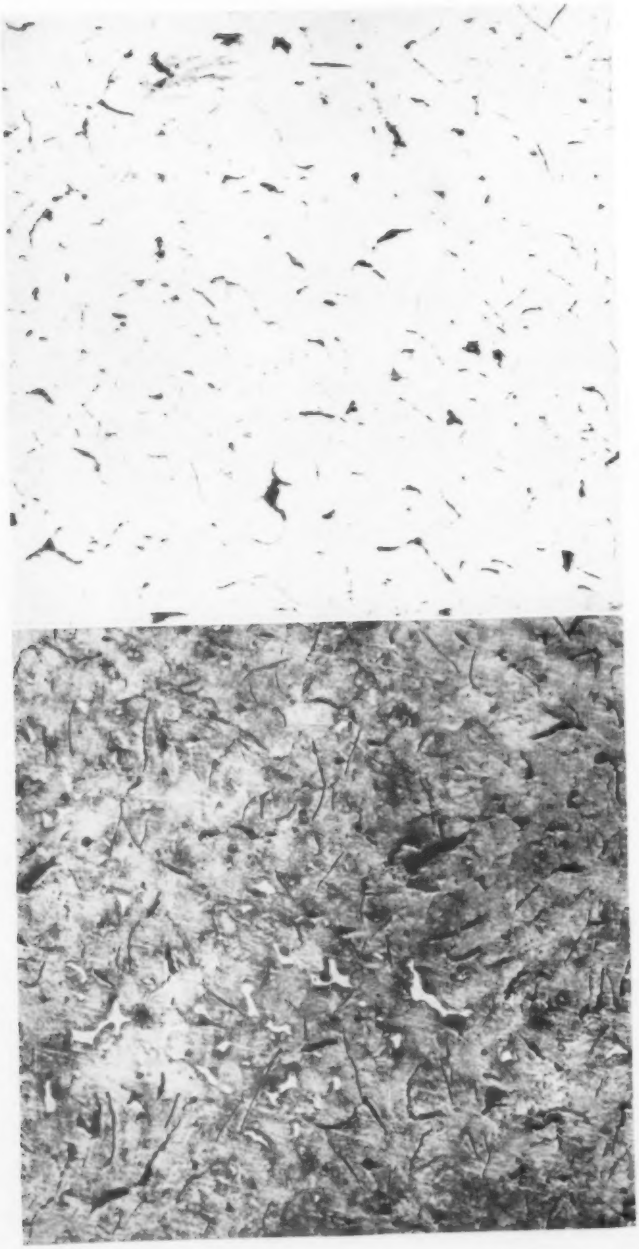

FIG. 27—AN IRON WITH EXCELLENT WEAR RESISTING CHARACTERISTICS. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

25. Figs. 21 Top and Bottom and 22 show normal graphite with a practically pure pearlitic matrix. Wear was 0.000701-in. per 10,000 miles.

26. In this bore, the iron is of the highly dendritic type, as shown in Fig. 23-Top. Fig. 23-Bottom shows that the dendritic graphite is associated with fine ferrite, as does Fig. 24. Wear was 0.003730-in. per 10,000 miles. It will be noted that the wear on

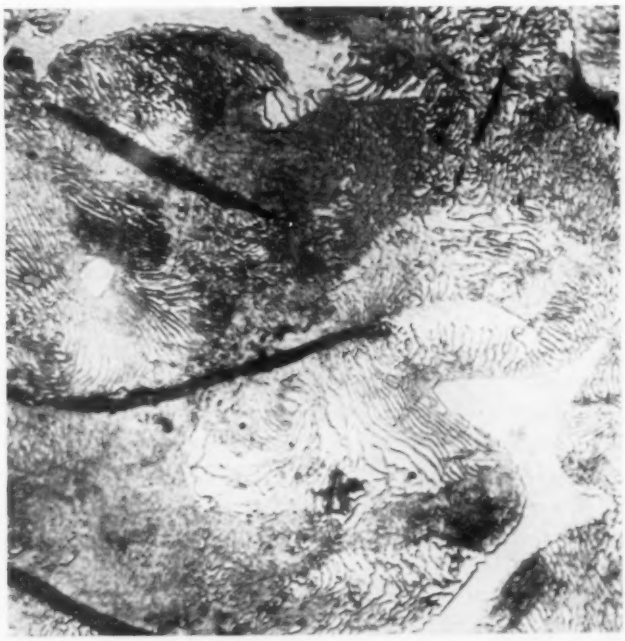

FIG. 28—SAME IRON AS FIG. 27, ETCHED WITH NITAL, 1000X.

Table 14

ANALYSIS OF GRAY IRON SPECIMEN USED FOR FIGS. 27 AND 28

Element	*Per Cent*
Silicon	2.01
Manganese	0.82
Total Carbon	3.40
Graphite Carbon	2.89
Combined Carbon	0.51
Sulphur	0.118
Phosphorus	0.176
Chromium	0.21
Nickel	0.23
Molybdenum	0.02

Brinell Hardness Number—201.

this bore is about five times that on the two preceding bores, although analyses are very similar and Brinell hardness is identical on all three samples. The only clew to the extreme difference in wear and structures may be the fact that the two preceding bores were of standard construction, while the one shown in Figs. 23 and 24 is an experimental design and it is quite possible that the cooling rate on this block was different from that of the others. This difference in cooling rate might have caused the dendritic structure and ferrite shown in Figs. 23-Bottom and 24.

Plant No. 4

27. This company runs their motor blocks on the hard side. This is borne out by the microstructures taken on their cylinder bores. Two blocks were submitted, each of which had had about 40,000 miles of usage.

28. Fig. 25-Top shows fine normal graphite. Fig. 25-Bottom shows small white spots of carbides. These are more visible at 1,000 diameters in Fig. 26. Wear was 0.000538-in. per 10,000 miles.

29. The microstructure of this bore is strikingly similar to the one shown just above made by the same company. Both of these blocks are of the low alloy type iron containing chromium and nickel. In spite of the presence of appreciable carbides, the blocks were readily machinable and have given very low rate of wear in service. Wear was 0.000467-in. per 10,000 miles on the block shown in Figs. 27 and 28.

RELATION BETWEEN COMPOSITION, HARDNESS, STRUCTURE AND WEAR

30. Certain facts are indicated as the result of this investigation.

(1) Irons with normal flake graphite give the best wear.

(2) Irons with large amounts of ferrite give poor wear; the wear increased directly as the amount of ferrite.

(3) Irons with the ferrite-fine graphite structure gave the worst wear.

(4) Irons with excessively coarse graphite gave porous bores, as will be discussed later.

31. An attempt was made to develop some relation between wear and structural components. The author has long felt that Brinell hardness offers a direct measure of resistance to wear in

motor blocks. However, the samples investigated at this time certainly do not indicate any such direct relation. It would appear that the actual structure has an important relation to the wear of the cylinder, and that the Brinell hardness is of importance in enabling the foundryman to control the structure. (Of course, Brinell hardness is very useful for other purposes, such as control of machinability.)

32. An attempt was made to plot hardness against wear, and combined carbon against wear, with negative results. However, when the approximate amount of ferrite in the structure of the iron at the position of the top ring was plotted against wear, the results were more interesting. In examining etched cast iron at 100 diameters, the amount of ferrite shown varies widely with the location in the block. However, in this case all the samples used for micrographic examination were taken at approximately the same position in like cylinders, and the measurement of the percentage of ferrite was a reasonable approximation at that spot.

33. It is obvious that the data available are not sufficient to establish any accurate curves, but they do show a trend. Although the curves illustrating the blocks from each plant are different, doubtless due to such factors as design, lubrication, foundry practice, composition, etc., it was noticed that in every set of blocks examined, increased wear accompanied increased ferrite. This is illustrated in Fig. 29.

34. From Fig. 29, one can at least deduce that on a series of cylinders taken from five different plants, the presence of ferrite in increasing amounts definitely increased the bore wear in the neighborhood of the top ring.

SPECIAL CASES

35. In examining a number of cylinders, a few special points arose which may be of sufficient interest to record.

Porous Bores

36. Occasionally, even in the best regulated plants, a bore is machined which exhibits small defects, and the block is scrapped as "porous bore." Frequently, this difficulty is caused by excessively coarse graphite. When this is the case, due to too high silicon or carbon, the machining operation tears out the iron between the coarse graphite flakes, giving a rough appearance to the bore. It

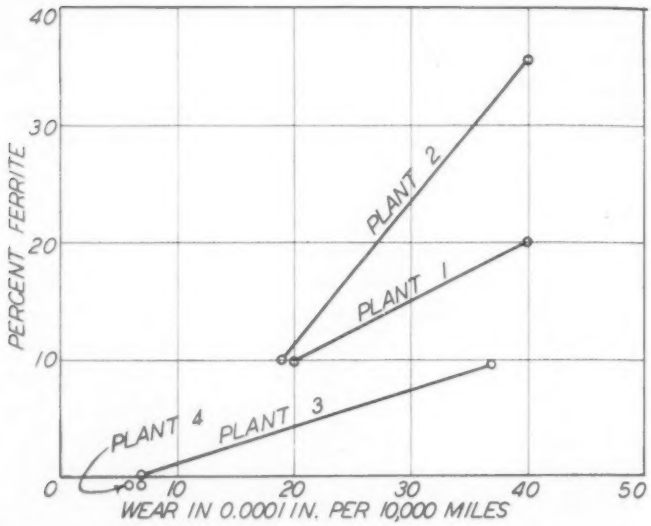

FIG. 29—CHART SHOWING THE TREND, BUT NOT DIRECT RELATION, BETWEEN PER CENT FERRITE PRESENT IN THE STRUCTURE AND WEAR.

would seem probable that the coarse graphite which causes porous bores, would not have a particularly detrimental effect on wear resistance.

37. Fig. 30 shows the structure at 100 diameters in two blocks which were scrapped for porous bores from two different plants. The obvious remedy for this condition is to keep carbon and silicon within limits, or to use one of the hardening alloys such as chromium or molybdenum.

Excessive Wear

38. As a definite check on results previously illustrated, which lead to the conclusion that the presence of ferrite is at least one cause of poor wear, a sample from another block examined microscopically may be of interest. This particular motor block showed excessive wear in service, and was re-bored. It was stated that the metal was so soft in re-boring that the block was scrapped.

39. Figs. 31 and 32 show the structure of that block. It will be noted that this bad wear was not accompanied by coarse graphite, but apparently was caused by large patches of ferrite.

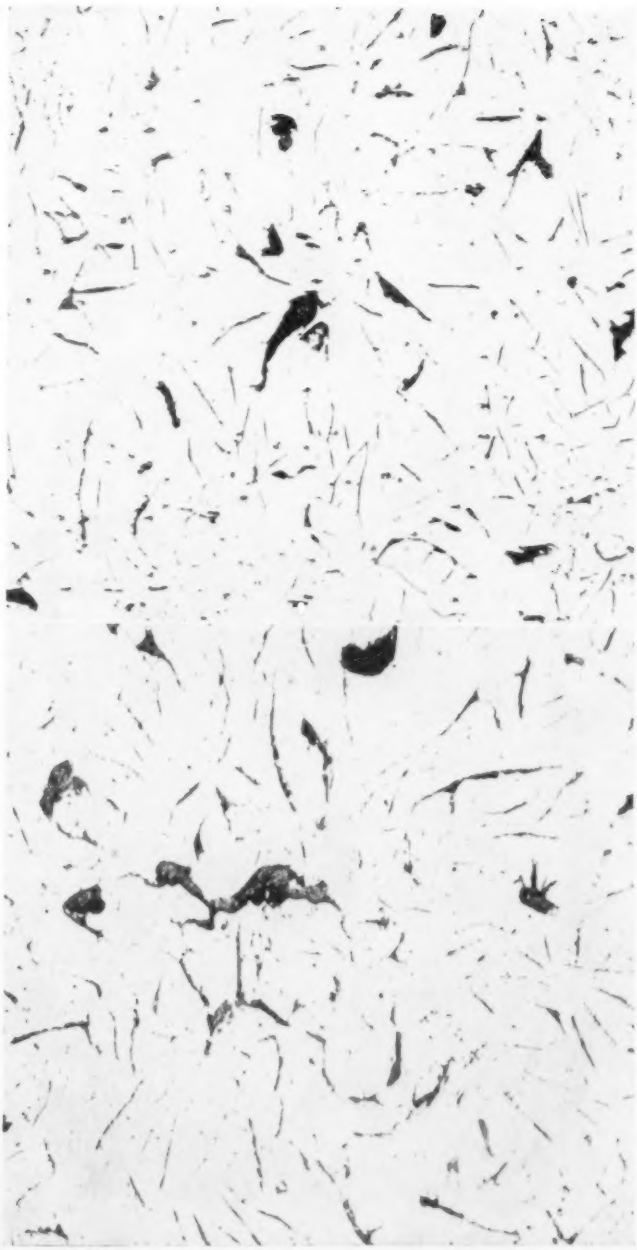

FIG. 30—STRUCTURE OF TWO BLOCKS WHICH WERE SCRAPPED BECAUSE OF POROUS BORES. UNETCHED, 100X.

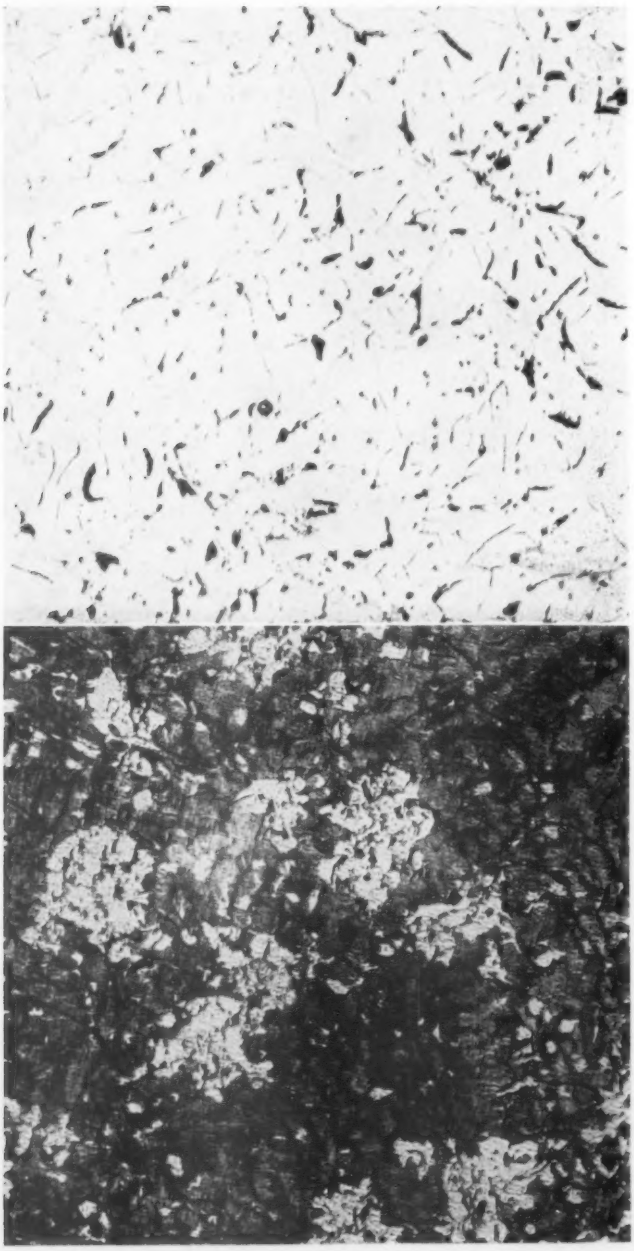

FIG. 81—STRUCTURE OF IRON WHICH SHOWED EXCESSIVE WEAR. TOP—UNETCHED, 100X. BOTTOM—ETCHED WITH NITAL, 100X.

Ferritic Rim

40. Most of the cylinders examined had been machined. However, the unmachined bore surface of several cylinders was photographed and in at least two cases, a continuous line of ferrite was found on the surface of the casting. Fig. 33 shows this continuous ferritic rim on the unmachined bore surface. Obviously, to avoid a very soft bore wall, it is necessary to machine through this ferritic rim. This surface phenomenon is another argument for the use of the microscope in the foundry.

CAUSES AND PREVENTION OF WEAR

41. There are almost countless causes of cylinder bore wear, and much has been written on this subject. In view of the many theories advanced in the literature, it is rather surprising to note that, up to recently, very little has been written about the effect of the actual structure of the bore metal on wear. In fact, the lack of this information has been pointed out by recent authors. In view of this condition, a brief digest of current ideas on the subject will be given, together with reference to the authors.

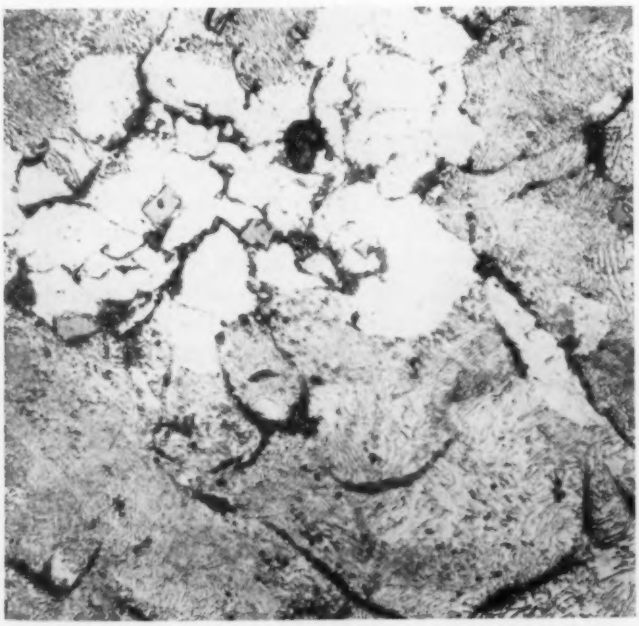

FIG. 32—SAME IRON AS FIG. 31, ETCHED WITH NITAL, 1000X.

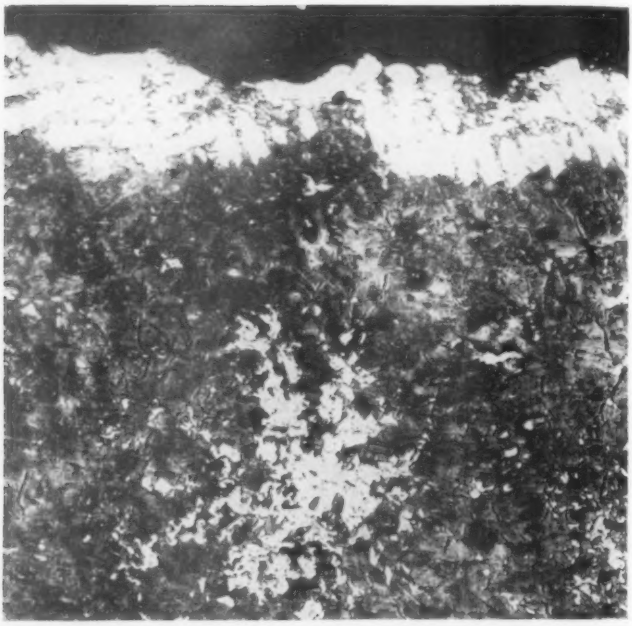

FIG. 33—MICROGRAPH SHOWING FERRITIC RIM ON UNMACHINED CYLINDER BORE.

Abrasion

42. It generally is considered that one of the most important causes of bore wear is the abrasion due to foreign particles in the lubricant, and that this effect has been largely controlled by the use of modern air filters. However, some abrasive dust still finds its way from the road into the cylinder, small abrasive particles are torn from the bore and from the rings, and particles of carbon are formed under conditions of high temperature, and drop into the cylinder. All of these abrasives get in the lubricant and cause bore wear. Recent papers have covered this subject very completely, and three[1] are cited for reference.

43. The effect of bore hardness on resistance to abrasion is controversial. Some authorities hold that bore hardness has no effect on abrasion. However, in service involving dusty conditions, it has been found that an increase in bore hardness very definitely decreased abrasive wear. It also has been established that liners of high Brinell hardness are very resistant to abrasion.

[1] Sparrow, S. W., and Scherger, T. A., TRANSACTIONS S.A.E. 1936, p. 717; Roensch, M. M., TRANSACTIONS S.A.E. 1937, p. 89; Yates, B. A., S.A.E. JOURNAL, Feb. 1939, p. 49.

44. Numerous laboratory tests have indicated that wear by abrasion is decreased as hardness increases. Very complete bibliographies of such tests are given in the "Symposium on Wear of Metals"[2] and by A. L. Boegehold[3].

45. In spite of more or less contradictory evidence, it would seem logical, in view of laboratory results and field experience, that the addition of some hardening agent, such as chromium or molybdenum, would increase resistance to abrasive wear, especially if the base iron had a tendency towards the formation of the extremely soft ferrite.

Corrosion

46. Corrosion of cylinder bores is undoubtedly one of the major causes of wear, but the relative importance of this item is doubtful. The English favor the idea that most of the wear is corrosive, and present some very convincing data [4, 5].

47. The general opinion seems to be that under conditions of cold starting, corrosion is an important phase of cylinder wear. When the rich mixture, often used in cold starting, comes to the motor, it immediately condenses, and dilutes to a great degree, the oil at the top of the bore. This film of oil may be very thin, due to draining off while the car was standing, and a slight washing effect by the condensed fuel may completely remove the oil. Then metal to metal contact takes place, and the bare iron is exposed to condensed acids from the fuel. F. F. Kishline and others have reported this condition[6].

48. It is well known that certain alloys add considerably to the corrosion resistance of cast iron, and their common use in cast iron exposed to acid corrosion, in the oil fields and elsewhere, would indicate that their presence in cylinders is equally effective in combatting corrosive conditions. Copper, chromium, and nickel are particularly effective[7].

Structure

49. A good deal of very valuable laboratory research work has been published recently, dealing for the most part with the

[2] Gillette, H. W., p. 16. Published by American Society for Testing Materials.
[3] Boegehold, A. L., *"Wear Tests and Value of Hardness Testing for Control of Product."* TRANSACTIONS, A.F.A., vol. 41, p. 575 (1933).
[4] Williams, C. C., TRANSACTIONS, Society of Automotive Engineers, p. 191 (1936).
[5] Taub, A., TRANSACTIONS, Society of Automotive Engineers, p. 229 (1938).
[6] TRANSACTIONS, Society of Automotive Engineers, p. 243 (1938).
[7] For complete data, see book entitled "Alloy Cast Iron," published by American Foundrymen's Association.

structure and wear resistance of piston rings and cylinder bores. Bancroft and Dierker[8] pointed out the effect of cooling rates in the formation of primary and secondary ferrite. This basic information has been of value in the study of cast iron cylinders.

50. P. S. Lane[9] has published the results of extensive laboratory wear tests, indicating that the ferrite-fine graphite structure is poorly resistant to wear.

51. It may be pertinent to note that the ferrite-fine graphite structures reported by Bancroft and Dierker, by Lane, by Yates and others, as giving poor wear results, are almost identical with the structures found to give increased cylinder bore wear in the present investigation.

52. It would appear that there is strong evidence that the ferrite-fine graphite structure is associated with excessive wear and the question of course arises, what is the best way to eliminate this structure?

53. In the first place, the engineer and designer can often design cast iron sections so that the cooling rate will automatically produce a structure which will be free from ferrite-fine graphite.

54. In the second place, the foundryman is able to modify the structure of his iron to a considerable extent by his methods for gating and pouring the castings.

55. In the third place, the metallurgist can control the structures to a great extent by his choice of mixtures and the use of suitable alloys.

56. In many cases, the ferrite-fine graphite structure can be completely eliminated by the addition of ferrosilicon or ferromanganese-silicon, or one of the other graphitizers in the ladle. Ladle additions of balanced alloys containing chromium and various graphitizers, are also giving very promising results, and several combinations of molybdenum-chromium and nickel-chromium are being successfully used.

57. Recent research work in England has shown that certain alloys, particularly chromium, molybdenum and tungsten, increase

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[8] Bancroft, R. H., and Dierker, A. H., TRANSACTIONS, American Foundrymen's Association, vol. 45, pp. 449-466 (1937).

[9] Lane, P. S., TRANSACTIONS, American Foundrymen's Association, vol. 45, pp. 157-199 (1937) also TRANSACTIONS, S. A. E., Oct. 1939, p. 413.

the thermal conductivity of cast iron. This new information may have bearing on the effect of these alloys on structure, as well as on motor operation.

Preferred Structure

58. The best cylinder bore structure is a matter of individual opinion, but having in consideration machinability, cost, and especially resistance to wear, the present author prefers a microstructure, at the position of maximum wear, consisting of an entirely pearlitic matrix with long thin flakes of normal graphite, no ferrite, and sufficient small particles of iron-chrome carbide to increase resistance to wear.

59. In closing, as in beginning, it is desired to emphasize that the microstructure of cast iron cylinder bores is an important factor in the control of motor wear, and that the best way to control this structure is by making routine microscopic examinations in the foundry laboratory.

Acknowledgments

60. The author wishes to acknowledge with appreciation, the kind cooperation of the following: Buick Motor Company, Cadillac Motor Car Company, Campbell, Wyant & Cannon Foundry Company, Chrysler Corporation, Climax Molybdenum Company, Ford Motor Company, Lakey Foundry & Machine Company, Olds Motor Works, Packard Motor Car Company, Pontiac Motor Company, and others. The author also wishes to acknowledge with appreciation the kind cooperation of his wife, Rebecca Hall Smith, in making photomicrographs.

DISCUSSION

Presiding: A. L. Boegehold, General Motors Research Lab., Detroit, Mich.

E. K. Smith: I want to say that in getting together this information, I did not have anything to prove. All I wanted to do was to try to get information, particularly on the effect of microstructure on wear. Where some of these data do not check, it is because that is the way the samples came in. We took a number of actual blocks that had been out in service on which there were accurate wear data. We made analyses and obtained microstructures. Very possibly in this discussion someone can point out the reasons for some of those apparently not checking.

One point I wish to bring up is that the structure is influenced by many things other than the analysis; for instance, the mixtures, the design, the rate of cooling, the way the cores are handled and the way the castings are shaken out, all have a big influence on structure.

I was told by one man that he had had blocks that were so badly pitted that they were actually listed as scrap. They ran them and got very good results. In several cases, highly ferritic blocks gave very good wear results.

Such points bring up many other things that are too complicated to discuss at this time. For instance, with a highly ferritic block, is there a work-hardening effect? If so, that changes the picture.

F. J. WALLS[1] *(Written Discussion:)* Mr. Smith has added materially to our knowledge of the causes and remedies for excessive cylinder wear and praise is due him for the excellent job he did in the preparation of this paper. As long as there are foundrymen, metallurgists and designers working together on this difficult problem progress will be made.

While the author does not draw any conclusions in his paper, he does list the facts as indicated by his investigation which point to the structure as being the principal factor in the control of cylinder wear. I am in accord with Mr. Smith's findings and suggested remedies, but I think the latter should be enlarged upon, especially when there is an opportunity for a foundryman to present to an engineer some idea of the magnitude of the problem involved in this so-called "structure control."

Briefly the author states, first, that the engineer can help to eliminate undesirable structures by designing sections that will cool at a proper rate and by this he not only means the section of the cylinder bore itself, but more probably its relation to the adjacent section. Thin cores between sections are usually bad actors from the standpoint of structural control.

Second, the foundryman can assist in this control by his gating and pouring temperatures. Sands, bonds, core washes, and mold facings, whose thermal characteristics we are just beginning to learn about, are also important in controlling structure of the metal poured into them or around them. Moisture, atmosphere, time in the mold after pouring, pressure and many other factors illustrate the complexities confronting the foundryman.

Third, that the metallurgist can control resulting structures to a great extent by his choice of raw materials in his mixture and the judicial use of alloys. This is true if the castings are of proper design, and the foundryman makes every mold and every core of the same density and composition, and pours every mold at the same temperature and gates the casting so the metal will be liquid in the proper place for feeding to take place when normal shrinkage sets in during freezing, etc.

[1] Metallurgist, International Nickel Co., Detroit, Mich.

The judicial use of alloys is an insurance policy to the metallurgist taken out on the structural life of a casting for which the premium is too frequently judged by the initial payment and not upon the ultimate benefit of the policy during a satisfactory life expectancy of a cylinder bore.

MR. SMITH: Mr. Lane is making new equipment for laboratory wear testing and, as I have all these original samples, I am going to give him, 10 or 12 of these sections cut from the bores next to where we worked with them. Mr. Lane will run the laboratory tests and see if they, in turn, check with the microstructures and the field tests.

P. S. LANE[2] *(Written Discussion):* When theories and laboratory findings are converted into real facts by service proof—valuable work has been done. This is particularly true in dealing with two such elusive subjects as gray iron structures and wear resistance. Hence, Mr. Smith is to be congratulated on his courage and thoroughness regarding this extremely valuable paper. Anyone who has attempted to analyze wear performance in connection with cast iron realizes the large amount of work and effort expended in accumulating the data submitted by Mr. Smith.

This paper is especially interesting to the writer in view of his efforts to obtain clues regarding wear resistance by means of accelerated laboratory wear testing. Some results of this work may be of interest in illustrating one case at least where laboratory indications were confirmed. This data has been taken from a paper previously given by the writer.*

Figs. 34 and 35 show the unetched and etched structures, taken at the bore surface of automotive engines. The structure in Fig. 34 is normal and gave a wear value (weight loss in milli-grams) of 12.3 mgs. The structure in Fig. 35 is abnormal, and its laboratory wear value, run under identical test conditions, was 26.8 mgs.

Fig. 36 shows the appearance of the bore surface of a cylinder with the abnormal ferrite structure at 5 diameters. This illustrates that the "disease" covers relatively large areas, in some cases the entire bore surface.

Fig. 37 illustrates the structure in the bore sections (from water jacket side to bore surface) from an engine casting wherein three different size cores were used, giving a light, medium and heavy section as cast. The bores were then machined to the nominal finish cylinder diameter and laboratory wear tests made at the wearing face. The results are as shown, and it is noted that the *5 C* section has a nearly all ferritic structure over its section, while *6 C* of the same "as cast" section size appears normal. Since these two bores were thinnest as cast, it indicates that relatively light sections are more prone to solidify in this freak system. This tendency has also been observed in other light section

[2] Research Engineer, Muskegon Piston Ring Co., Muskegon, Mich.

* *"Bore Wear from the Viewpoint of Materials,"* World Automotive Engineering Congress, Society of Automotive Engineers, San Francisco, June 8th, 1939.

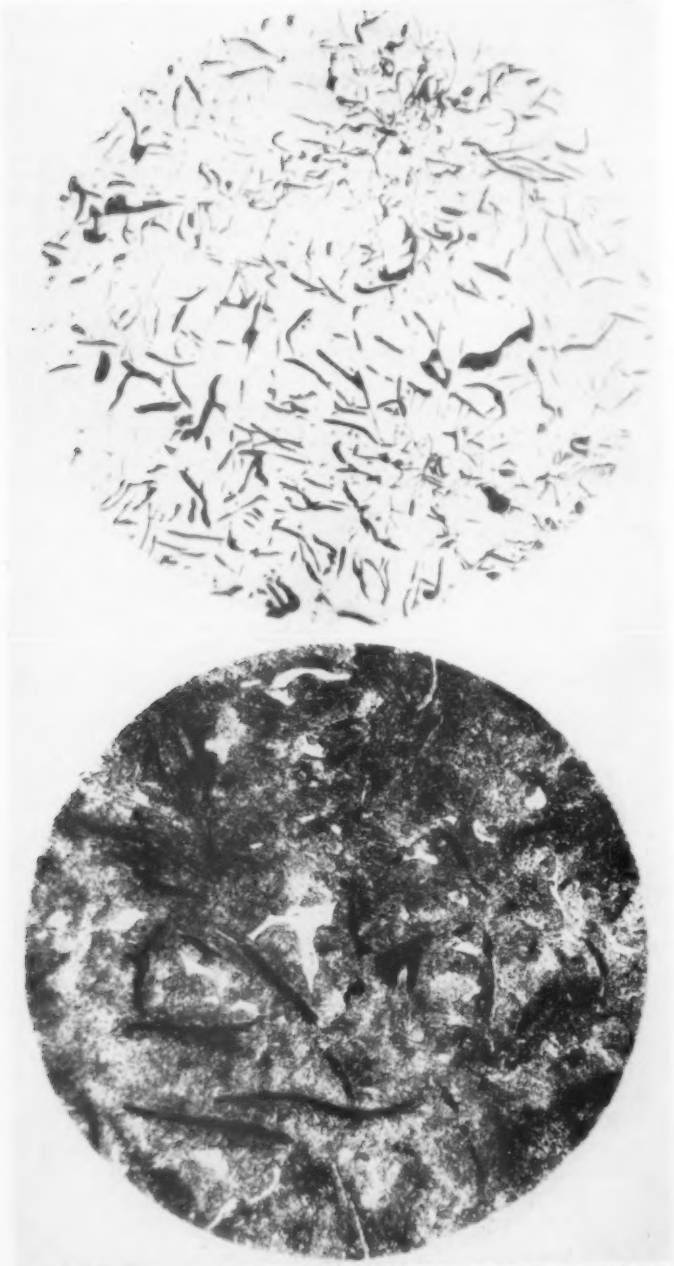

FIG. 34—BORE STRUCTURES. CYLINDER "A"—NORMAL. WEAR VALUE—12.3 MG. TOP—UNETCHED, X50. BOTTOM—ETCHED, X200.

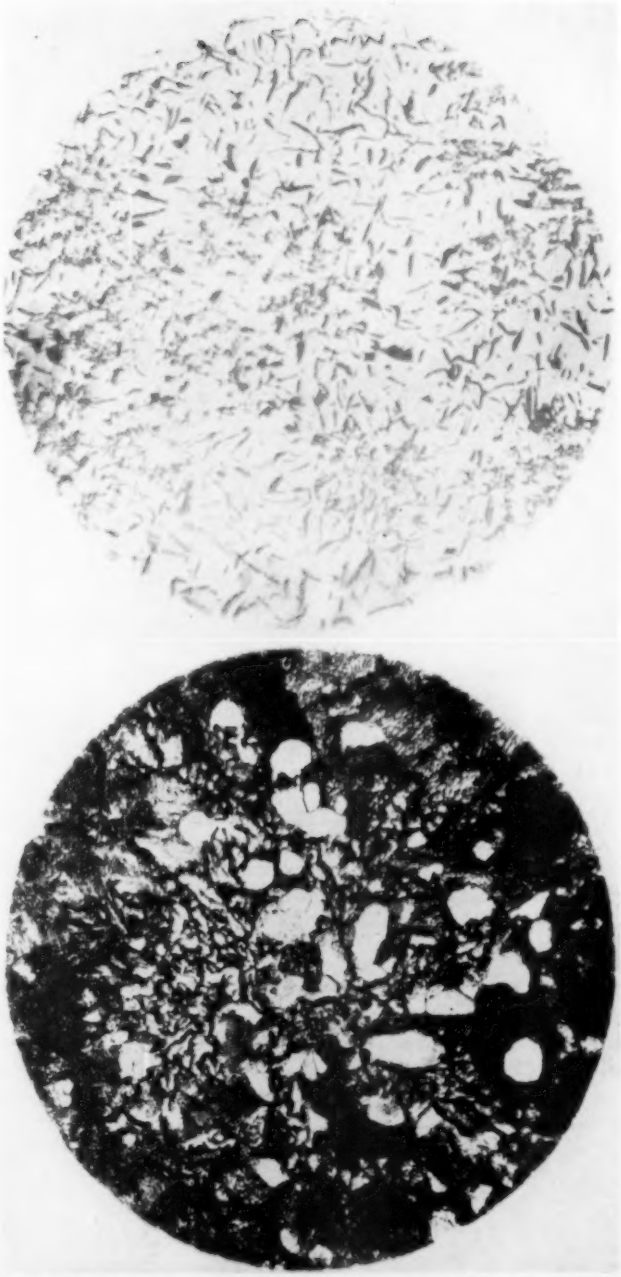

FIG. 35—BORE STRUCTURES. CYLINDER "B"—ABNORMAL. WEAR VALUE—26.8 MG. TOP—UNETCHED, X50. BOTTOM—ETCHED, X200.

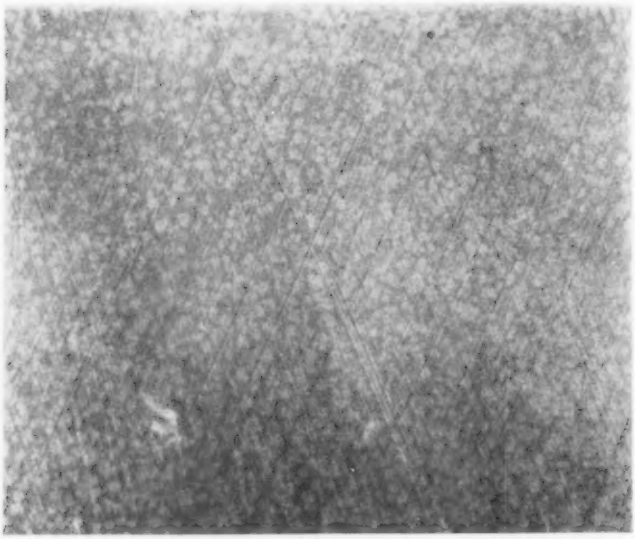

FIG. 36—LARGE AREA OF BORE SURFACE WITH ABNORMAL STRUCTURE X5 ETCHED.

castings and by other investigators. The very high wear value obtained with the *5 C* specimen coincides with Mr. Smith's findings.

The above data would indicate that the abnormal structure may exist in one or more bores of the six or eight, while the remaining ones in the same block casting are normal. This is believed to be due to critical cooling rates determined by many foundry and design factors. Also, the "as cast" metal thickness or section size itself has an influence, and an alteration in molding, pouring or gating may improve the condition. High pouring temperatures, over 2800° F. are believed to accelerate the tendency to solidify with the abnormal ferrite structure, at least in the section size in question. Figs. 23 and 24 in Mr. Smith's paper may be an example of this.

The attack on a problem of this type would obviously be different for each individual foundry. The first step would be to learn if such undesirable structure is present, and its extent. Low power observation of large areas and section is suggested. Next, an alteration in design, section or pouring and gating practice is in order, together with tests at lower metal temperatures. In one instance, improvement has been reported by changing the time and location of stripping or shaking out. After a thorough check along these lines to learn the extent of the "infection," alloy additions should be investigated—those with carbide stabilizing effects appearing most logical.

Turning now to the question of why such "ferrite—fine graphite" structures result in higher wear. It is the writer's opinion that the harm

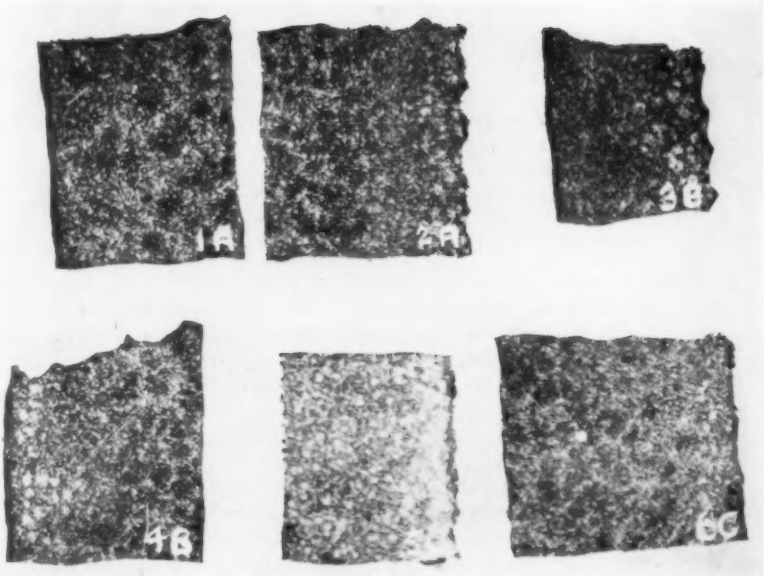

FIG. 37—BORE SECTIONS AT X5 MOUNTED POLISHED AND ETCHED AS A SINGLE SPECIMEN, INDICATE STRUCTURAL VARIATIONS IN THE ENGINE CASTING WITH DIFFERENT SIZE CORES AND SECTION THICKNESS

Silicon	1.80 per cent
Sulphur	0.12 per cent
Phosphorus	0.25 per cent
Manganese	0.75 per cent
Total Carbon	3.25 per cent

	Small Cores		*Medium Cores*		*Heavy Cores*	
	Heavy Sections		*Medium Sections*		*Light Sections*	
	1A	*2A*	*3B*	*4B*	*5C*	*6C*
Rockwell "B"	88.5	88.9	86.4	87.5	85.4	89.4
Wear, Mfg.	18	20	22	22	46	22

comes not so much from the presence of the ferrite itself, but rather from the fine "sooty" graphite associated with it. This "eutectic-like" form of graphite seriously interrupts the continuity of the metal, resulting in ready fragmentation or powdering away. Some very good wearing iron structures have contained limited amounts of the *normal* ferrite constituent.

Mr. Smith's comments relative to the hardness-wear relation are in accord with other investigators. He reports bores with hardness of 176 and 201 Brinell, both having excellent resistance to wear. Approach to bores of higher Brinell hardness should be made on the basis of structural alteration mainly, rather than by hardness, as certain dense relatively hard structures (240-280 Brinell) have, in some applications, proved rather unsatisfactory.

The range of chemical analyses used in cylinder irons is as given below, this having been compiled from the data given in the paper under discussion.

	Per Cent
Silicon	1.76 -2.57
Sulphur	0.084-0.15
Phosphorus	0.12 -0.30
Manganese	0.56 -0.87
Total Carbon	2.94 -3.48
Brinell	146-201

In conclusion, it is believed that Mr. Smith's paper should prove of much interest to automotive engineers, as well as to foundrymen. Many extensive fleet tests have been run to learn the effects of oils, air cleaners, oil filters, *etc.* on wear, without giving due recognition to the metallurgy of the cylinder bores. Some of these results have proved disappointing, due to the difficulty of controlling all the variables. Certain of these variables existed with the cars and engines used in Mr. Smith's tests, and yet his results show good correlation on the basis of structural differences. Hence, one would suppose that the importance of the metal structure in the bores is more significant than many imagined. The work now being carried out in connection with metal finishes, surface treatments, platings, *etc.* in automotive engines should also encompass proper regulation of the entire body or matrix of the metal in this quest for wear retardment. The need of close cooperation between foundryman, metallurgist and engineer is manifest.

Z. T. CRITTENDEN[3] *(Written Discussion):* Mr. Smith is to be congratulated on his very excellent paper. We consider the subject of wear tests seriously, as they are very hard to duplicate although Jominy has shown some rather uniform results with different samples of the same iron.

We quite agree with the author that there is a relationship between the composition, hardness and structure and the wear of the iron in bores of a cylinder block, and that irons with large amounts of ferrite give poor wear. We have also analyzed several cylinder blocks which had 40,000 to 50,000 miles of hard service and found the iron to have a similar structure as that shown in Figs. 17 and 18. The Brinell hardness, and analysis were the same except that the chrome and nickel contents were 0.20 and 0.15 per cent respectively. The bores did not show excessive wear, in fact we were surprised that an iron of this hardness would stand such a severe grind without more.

A high silicon content does not necessarily mean poor wearing iron, providing other conditions are favorable, such as the chemical analysis, a proper cooling structure, a good Brinell hardness, *etc.* Such a contrast is seen in the two sets of micro photographs, and the accompanying analysis, as shown in Figs. 15 and 16, Table 8, and Figs. 19 and 20, Table 10. In fact, the iron showing the highest silicon content shows the least amount of wear.

[3] Metallurgist, Pontiac Motor Co., Pontiac, Mich.

If possible, it would be interesting to compare the chemical analysis and hardness of the iron shown in Fig. 31 with that of Fig. 23 as they both have the same type of structure and both show excessive wear.

There is no doubt and we quite agree with the author, that microscopic examination of cast iron offers a valuable means of controlling the structure as well as other properties which cannot be obtained in any other manner. We are very glad that we have the opportunity to take advantage of it.

G. P. PHILLIPS[4]: Mr. Smith has done an excellent piece of work and his warnings and cautions are very much in order. Fig. 29, showing the percentage of ferrite against wear, illustrates the necessity for caution in trying to analyze the correlation between wear and structure. It shows that the irons with 10 per cent ferrite had a variation of 100 per cent in the rate of wear, and that same large variation of 100 per cent held true in irons of still higher variation in the percentage of ferrite. A 100 per cent variation in wear results is certainly a huge figure and something we should keep in mind when we interpret, or try to interpret, these correlations between structure and wear.

The point I wanted to bring out in Fig. 29 is that in Plant 3, at the top of the curve, we have about 10 per cent ferrite and about 0.037 in. wear. In Plant 1, with 10 per cent ferrite, we have about 0.020 in. wear or roughly half as much. Again, in Plant 1, at the top we have 20 per cent ferrite and about 0.040 in. wear, and in Plant 2, with some 35 per cent ferrite, we again have 0.040 in. wear.

MR. SMITH: That is a good deal the matter of design, is it not? Of course, we did not cover more than a fraction of the blocks here, but we noticed that in a given company, the wear would be more or less comparable in all the blocks. In another one, it might be a little bit higher. But where there was no ferrite, there was very low wear. With the same design, cooling rate, foundry practice, mixtures, etc., the ferrite raised the rate of wear. Of course, the subject is so complicated by design and mixtures that it is difficult to draw exact conclusions. These are merely trend curves in Fig. 29.

Another thing that would throw things off is that 6 different curves can be drawn for the 6 cylinders in one block. For instance, bore No. 1 wears at a different rate in some blocks from the other bores, so we always tried to take the No. 2 bore.

CHAIRMAN BOEGEHOLD: In reference to the statements about wide variation in amount of wear at constant combined carbon, I wish to cite a case where even greater divergence existed between wear and combined carbon. We examined a cylinder block returned from Great Britain where it had been in service. It showed considerable wear so we looked at the microstructure of the various cylinders, all of which had practically the same amount of wear. Apparently this block had been re-

[4] Chief Metallurgist, Automotive Foundry Div., International Harvester Co., Chicago, Ill.

paired in the foundry by welding prior to installation because No. 1 cylinder was entirely ferritic; there was not a particle of pearlite in it. The remaining cylinders were all completely pearlitic, containing no ferrite. They all, including the ferritic cylinder, had practically the same amount of wear. So instead of a variation from 10 to 35 per cent ferrite having the same amount of wear as depicted by Mr. Smith's chart, the example just cited shows a variation from 0 to 100 per cent ferrite for the same amount of wear. So circumstances alter the results, certainly. The circumstances responsible for the wear in this case were presumably favorable to corrosive type of wear which does not recognize variation in amount of pearlite present.

MEMBER: Did the author find any correlation between the amounts of other alloys present along with the ferrite?

MR. SMITH: We found relatively little effect of the different alloys in these particular blocks. Generally speaking, the ones that we examined had small amounts of alloys, particularly nickel-chromium. I will just say roughly, the ones that gave the best wear had small amounts of alloys in them. On the other hand, we had some which gave excellent wear with no alloys.

Perhaps with a little prejudice, my personal opinion is that you can make a good block with any preferred structure, without using alloys, but I believe it would be easier to get a preferred structure by using alloys.

GOTTFRID OLSON[5]: Would it not be a very good thing if it were possible to continue this work and have something further on it next year. If it should be continued, it would be well to include in whatever work is done the mixes used to obtain the values. I would suggest that, if possible, Mr. Smith include in the final paper as printed the mixes that were used in these various blocks. We know that the cupola operation and the mixes are of at least as great an importance as are the analyses. In fact, I would go still further by saying that, looking at analyses alone, including the microstructure, we will not learn all there is to be learned about it. Mr. Smith said one interesting thing, namely, that microphotographs can be produced to prove anything. Fortunately Mr. Smith is in a position where he does not need to prove any particular idea or thing, but if one is not careful enough in doing this work, he is liable to produce results that will be misleading.

MR. SMITH: That is a very interesting point about the mixtures, and I certainly agree that the mixtures have an important bearing on the structure and possibly on the wear, independent of the structure, although I am not sure about that. In this case, it would have been quite difficult to report all these points. These people cooperated very finely by letting us have the blocks and while we recognize the point that the mixture would have an effect, it seems to me it would be asking too much to include all the raw material data. There was so much ground to cover

[5] Foundry Engineer, National Founders' Assoc., Chicago, Ill.

that we thought if we just covered the blocks as we received them, some one else could go on from there. We purposely kept away from design, lubrication, *etc.*, all of which have an enormous effect on the wear.

MR. OLSON: I would also, in the work that eventually will be continued, include something on cupola operations, because that ties in with cupola charges. We know quite well that by certain cupola operations, we can produce certain irons, and that should be included.

H. N. MYERS[6]: Mr. Smith has covered the cylinder end of the study very well, but I believe there is something further that should be done. The mating of materials greatly affects the wear characteristics. This has been recognized for quite some time. In the last statement that Mr. Smith made in regard to his recommendations as to structure, he stated there should be a few chromium-iron carbides in the structure along with the flaky graphite and the normal pearlitic structure. We have done a little wear testing and along those lines we usually find that if there are a few carbides present, certainly the ring wear goes up. I do not believe this discussion would be quite complete if we did not consider the effect of the structure which you are producing on ring wear.

MR. SMITH: I believe Mr. Boegehold could answer that better than I can. I imagine that is more or less a question of economics. Would it be better to have a bore that would go 50,000 miles without any appreciable cylinder wear and change the rings, or would it be better to try to get a block that would not wear either the rings or in the bore?

MR. MYERS: It has been our experience that there are cases where a minimum of wear can be obtained; that is, the total wear on both the rubbing surfaces becomes a minimum. In other words, you perhaps would want to increase the wear on the ring surface, certainly, from the standpoint of economy, but then there are certain combinations that produce the most ideal condition. That was the point I wished to make.

CHAIRMAN BOEGEHOLD: By all means we want to get the minimum wear on both the rubbing surfaces, so we have to take both of them into consideration. We have cases of wear testing that have later been verified in field tests where a reduced rate of wear on the cylinder liner resulted also in reduced wear on the piston rings. We do not want to increase the wear resistance of the liners, certainly, at the expense of the piston rings.

F. G. SEFING[7]: Mr. Olson brought up a rather interesting point having to do with the causes back of producing these bad structures. Inasmuch as there are so many different compositions that have to be contended with, involving many varieties of mixtures, there is nothing much we can do about the compositions and mixtures. I should rather call attention to the fact that there are methods of handling the molten metal to prevent the bad structures. Proper pouring temperatures, proper pouring speeds, proper ladle treatments and so on all affect the produc-

[6] Metallurgist, Sealed Power Corp., Muskegon, Mich.
[7] International Nickel Co., New York City.

tion of desired microstructures. I rather think that this is the better approach to the problem we have on hand.

We have done considerable work in machine tool structures as well as cylinder liners, toward producing the type of structure which Mr. Smith presented this morning as being desirable. Although it would be interesting to learn the cause back of these good and bad structures, I should rather call attention to obtaining the type of structure we want independent of the compositions and mixtures used.

G. W. ZABEL[8]: In conjunction with what Mr. Sefing had said, there are other factors that should be taken into consideration. The same metal poured into the same pieces with a change in the method of gating will definitely produce a difference in structure, as shown by Mr. Smith. In support of that statement, I have made thousands of test bars connected to castings and those test bars have been subjected to physical tests from the standpoint of Brinell and tensile strength. The Brinell hardness would go as high as 400 on the test bar and drop to 250 on the castings. Changing the gating in that test bar would bring the Brinell down to that of the casting, if it was gated correctly.

The structure in the cylinder bore is going to depend to a considerable extent on the way it is gated. The iron cannot be allowed to lay against the mold surface and solidify immediately without definitely changing the Brinell hardness; and, of course, in changing the Brinell hardness, the structure is changed to a great extent.

MR. SMITH: Mr. Walls brought up the same thing in his written discussion when he pointed out that this paper did not cover the very important effect of foundry practice. I told him the paper was long enough and that it would take some expert foundryman to cover that phase of it. I hope some one will do it.

V. A. CROSBY[9]: In order that we may not go away from this session too well satisfied that the elimination of ferrite is the positive solution to the problem of wear in cylinder blocks, I would call your attention to certain structures of 220 Brinell containing 50 per cent ferrite which exhibited wear resistance in the as cast condition comparable with a heat treated alloy iron of 500 Brinell. These tests were made by one of the large motor companies in an effort to find the best cylinder liner material for gas powered engines.

From Mr. Boegehold's remark relative to wear in ferrite vs. pearlitic cylinders, as mentioned in the fore part of the discussion of this paper, one might be constrained to believe that equal results could have been obtained by plotting wear against circumstances instead of ferrite. In other words, the factors surrounding the operation of any motor are of much more importance than the structure or composition of the material within the range of 170 to 250 Brinell.

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[8] Superintendent of Foundries, Fairbanks Morse & Co., Beloit, Wis.
[9] Climax Molybdenum Co., Detroit, Mich.

E. K. SMITH *(Author's Written Closure):* The author wishes to thank the discussors of this paper for their most interesting and constructive criticisms. Messrs. Walls, Olson and Zabel have pointed out that structures can be controlled by foundry practice. Mr. Zabel's remarks on control of hardness by gating methods are particularly interesting.

It is recognized that foundry methods, mixtures, lubrication, design of motor, fuel, operating conditions and countless other variables have their influence on the wear of the bore. However, the author is inclined to disagree with Mr. Crosby's statement that "the factors surrounding the operation of any motor are of much more importance than the structure or composition of the material within the range of 170 to 250 Brinell." The author believes that field tests, laboratory tests and automotive experience indicate that both structure and composition have an important bearing on resistance to wear.

The author wishes to thank Mr. Lane particularly, for his very comprehensive addition to this paper. It is gratifying to note that Mr.

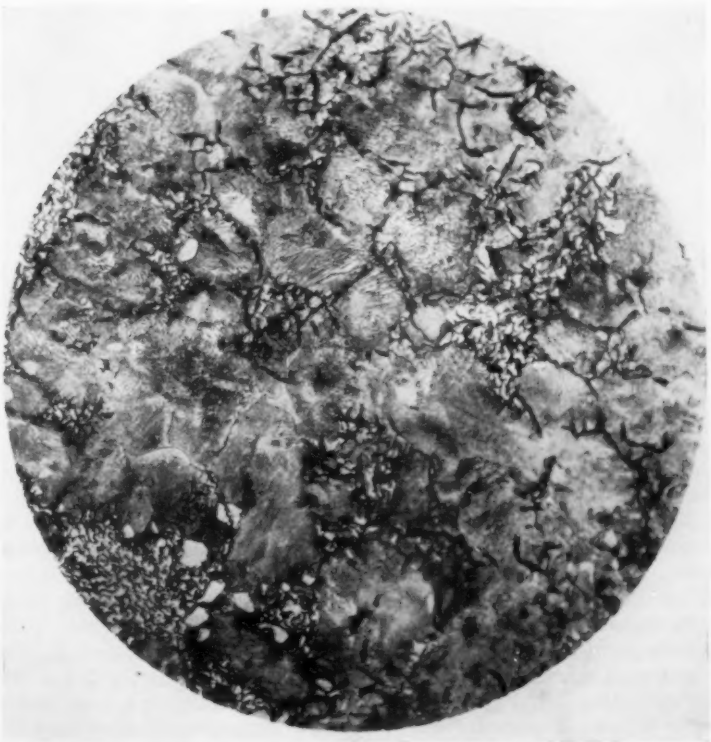

FIG. 38—STRUCTURE IN ARBITRATION BAR OF NORMAL CYLINDER IRON. REDUCED 3/7 IN REPRODUCTION

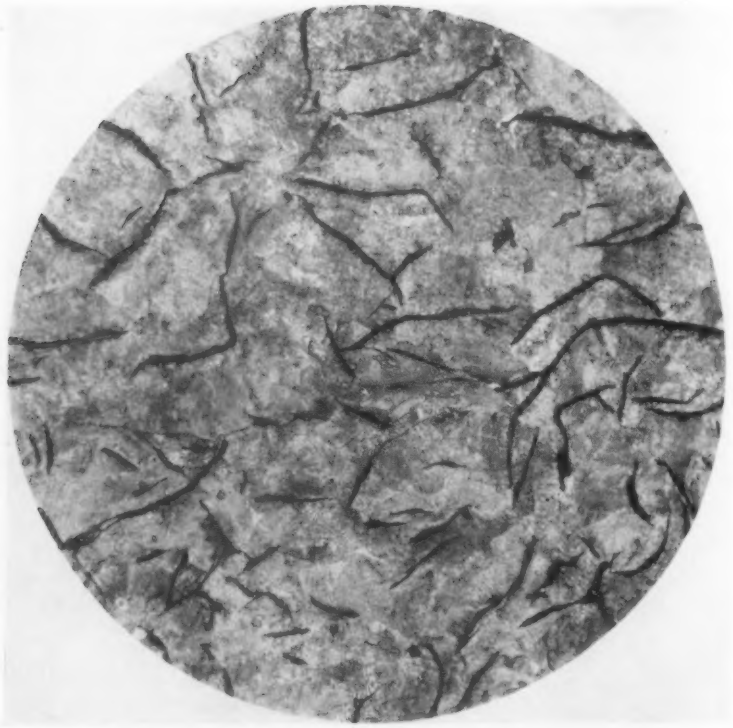

FIG. 39—STRUCTURE OF TEST BAR OF SAME IRON AS FIG. 38 WITH ADDITION OF "BALANCED" ALLOY. REDUCED 3/7 IN REPRODUCTION.

Lane's exhaustive tests, in many instances, check the results reported by the present author.

Admitting that any number of variables affect structure and wear, it must also be admitted that it is not always simple to change the structure in the direction desired. For instance, it might be difficult to change the design of the block, or its cooling rate in the mold, or even its pouring temperature. For this reason, considerable work done by different organizations on ladle additions is particularly valuable at the present time. It is now known that practically any desired structure can be obtained by a suitable ladle addition. Shown below are photomicrographs illustrating the complete change from a structure of fine graphite-ferrite to a completely pearlitic structure with normal graphite by means of a small addition of a "balanced" alloy in the ladle. The photomicrograph in Fig. 38 illustrates the structure in an arbitration bar of a normal cylinder iron. Fig. 39 illustrates another test bar poured from the same ladle of iron after a small addition of "balanced" alloy had been added to the metal.

A Sand Control Program in a Malleable Foundry

By D. F. Sawtelle*, Branford, Conn.

Abstract

This paper is a report of progress made after many futile attempts to change the old customs of a malleable foundry using natural bonded molding sands. This was accomplished after drawing a true picture of existing sand conditions as plainly shown by sand testing. It should be of special interest to foundrymen who still doubt that the installation of sand testing equipment can help them in solving many of their problems.

Old Customs

1. It has been the custom for many years to buy sands for use in the foundry by name or number. Foundrymen in all parts of America, and especially in the New England states, are familiar with the Albany molding sands in which many thousand tons of good castings have been made.

2. Many foundries are faced with the problem of pouring castings varying from a small fraction of an ounce to many pounds in weight.

3. From this problem has grown the custom of buying a fine sand which will take care of the larger percentage of the work and then mixing a coarser sand with it to "open it up."

4. In these foundries, there may be from ten to one hundred separate sand piles with nearly as many different properties as numbers, due to the mixing of two entirely different types of sand in varying proportions.

5. The reconditioning of these many piles for reuse may consist of the addition of water by the individual molders in what they estimate to be the proper amount as learned by experience,

* Metallurgist, The Malleable Iron Fittings Co.

Note: This paper was presented at a Malleable Session of the 44th A.F.A. Convention, May 7, 1940, Chicago; Ill.

and sometimes sad experience, followed by a sand cutting machine. This is moisture control and sand preparation as still practiced by many foundries today.

6. The strength of each individual pile depends on whether the molder added new sand when needed or obtained a false strength, which leads only to blows and other troubles, by throwing on a little extra water. In this way, strength was controlled, or perhaps it would be better to say went uncontrolled until trouble developed.

7. The above conditions due to old customs existed in the author's malleable foundry long after definite progress had been made in the steel foundry connected with the same company.

PROGRESS IN THE STEEL FOUNDRY

8. Early in 1931, the superintendent of the steel foundry asked the management to install sand testing equipment in the chemical laboratory, consisting only of permeability and a green compression strength apparatus. The laboratory was already equipped with scales and a drying oven for moisture determinations.

9. The following figures were obtained on the sand in use March 19, 1931.

	Facing Sand	*Backing Sand*
Moisture, per cent	3.3	3.1
Permeability	330	420
Green Compression Strength, lb. per sq. in.	4.1	2.6

10. The troubles at that time consisted of sand sticking badly to the castings, pin holes, poor surface of the castings and weak sand.

11. The sand was a mixture of a natural bonded sand, silica sand and clay.

12. Since that time, a sand reclamation apparatus has been installed for the removal of fines. This was followed by a change to 100 per cent synthetic sand. Recently our steel castings have received the compliment of having a better finish than many gray iron castings of like size, and in one instance, the remark came from a gray iron foundryman. As a matter of course, the other

equipment was added to the initial sand testing equipment purchased.

13. The figures for moisture, permeability, and green compression strength today are about as follows; with an entirely different grain size and distribution:

	Facing Sand	*Backing Sand*
Moisture, per cent	4.0	4.0
Permeability	170	140
Green Compression Strength, lb. per sq. in.	8.5	6.5

Different Problems in Each Foundry

14. The steel foundry, since the first tests were made on its sand, has been equipped with complete conditioning apparatus, consisting of magnets for removal of metal, screens for the separation of oversize and undersize particles, air suction for the removal of silt and a muller to mix in the chosen binders and water. The malleable foundry had nearly one hundred individual sand piles and only a sand cutter as conditioning apparatus.

15. It did not seem that there would be enough gained by spending the necessary time and money to test the great number of individual piles for moisture, permeability, and green compression strength, nor any practical way of controlling these properties in the malleable foundry.

Attacking the Problem in the Malleable Foundry

16. Tests for clay content, average grain size, distribution, permeability, green strength, and moisture were made on the stock piles and on several of the individual molder's piles. The results were so amazing, in fact almost unbelievable, that an incentive was furnished to go ahead with the work.

17. The sand that was known as a No. 0, turned out to be a weak No. 1, and that known as a No. 1 proved to be a strong No. 0. The coarse sand, which had been mixed in many of the piles to "open them up," had failed miserably in this direction, but had done a wonderful job of ruining grain distribution and, therefore, casting finish.

18. The question then was how to show the true conditions to the management and the foundry superintendent who were un-

familiar with sand testing. It would have been useless to talk in terms of A. F. A. grain fineness numbers, and especially A. F. A. grain distribution numbers.

19. It was decided to make up a number of test tube racks, wash the sands for clay extractions, make the usual screen tests and put the sand from each screen in a separate test tube arranged from left to right in order of the screen numbers as is shown in Figs. 1, 2, 3 and 4.

20. After sufficient evidence had been accumulated, a meeting was called, at which the management was represented by the general plant superintendent, the foundry by the malleable foundry superintendent and assistant superintendent. The testing laboratory by the author, and Gottfrid Olsen, foundry engineer connected with the National Founders Association. His presence and substantiation of claims made, was of great help in obtaining permission and the whole hearted cooperation of those present in making the necessary changes in our sand practice.

SAND TESTS PRIOR TO CHANGES IN PRACTICE

21. Fig. 1 is a rack of test tubes, showing the amounts on the different A. F. A. screens of a sand known as a No. 1 and which actually was a fairly strong No. 0. The first test tube on the left contains all the sand on the 6, 12, and 20 mesh screens. The sand on the 30, 40, 50, 70, 100, 140, 200, 270 mesh screens and the material on the pan being arranged in order reading from left to right. Fig. 2 shows the amounts of sand on the different screens of a No. 0, which proved to be a rather weak No. 1. Fig. 3

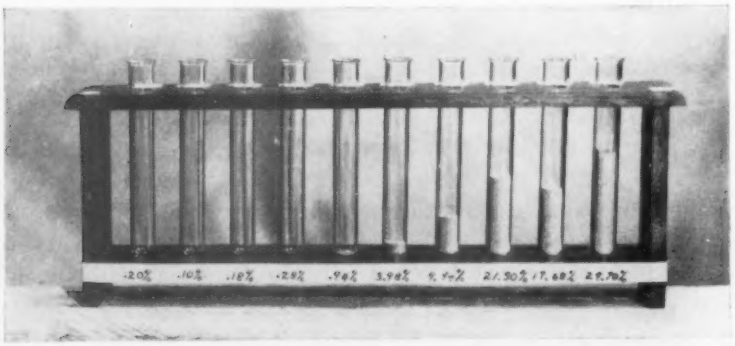

FIG. 1—SCREEN TEST OF SAND DESIGNATED AS ALBANY NO. 1—A.F.A. CLAY, 15.7 PER CENT; A.F.A. GRAIN FINENESS NUMBER, 199.

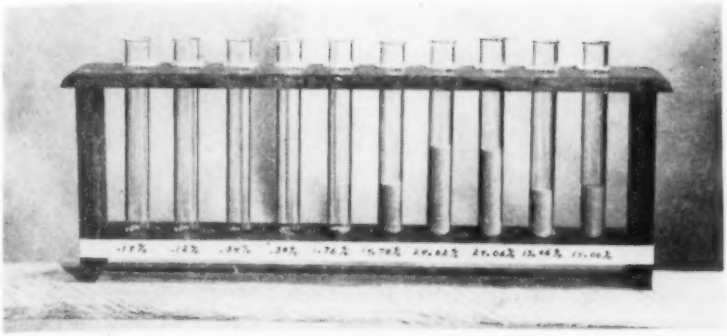

FIG. 2—SCREEN TEST OF SAND DESIGNATED AS ALBANY NO. 0—A.F.A. CLAY, 6.74 PER CENT; A.F.A. GRAIN FINENESS NUMBER, 147.

shows the exceptionally poor distribution resulting from mixing the so-called coarse sand with the No. 1 Albany to "open it up." There was none of this coarse sand available to use as an exhibit in test tubes but its effect on grain distribution can readily be seen by comparing Fig. 1 with Fig. 3.

22. There were very few molder's sand piles where the moisture was under 8 per cent. The average permeability was about 12 and the green compression strength varied from 3.5 to 5.0 lb. per sq. in. The higher strength was obtained only by large proportions of the "coarse" sand which ruined the none too good grain distribution of the so-called No. 1 sand and gave only one or two points more permeability to the mixture. An exaggerated analogy of the fact that a coarse sand will not open up a fine sand may be found in the statement "You can not raise the permeability of a bag of silica flour by mixing it with a bag of marbles."

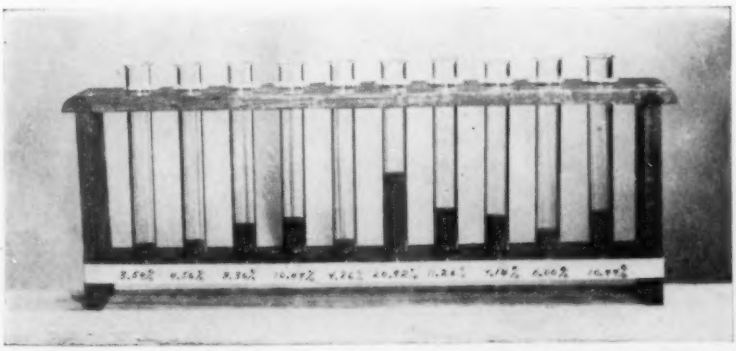

FIG. 3—SCREEN TEST OF A HEAP SAND OF THE NO. 1 ALBANY SAND WHICH HAD BEEN "OPENED UP" WITH A COARSE SAND—A.F.A. CLAY, 11.08 PER CENT; A.F.A. GRAIN FINENESS NUMBER, 107.

OUTLINE OF NEW SAND PROGRAM

23. As a result of the meeting, it was decided to purchase, by specification, a stock sand of 12-15 per cent A. F. A. clay content and 15-20 permeability and a good grain distribution. To obtain a sand to meet these few, and what we thought to be entirely reasonable, specifications was not a simple matter. While there are many fine grades of Albany sand with 12-15 per cent clay, they are usually under 15 permeability. As a general rule, the higher the clay content in Albany sands, the higher also is the silt content and the lower the permeability. There are also many grades of Albany sands where the permeability is above 15, but they are usually low in clay content. Of course, there are exceptions due to too wide a spread in grain distribution, but this was not wanted.

24. It was decided that the most important point was to specify what was wanted and then by testing see that the material measured up to these specifications. It seemed futile to spend time making hundreds of tests on sand piles which would only show what poor sand had been bought and how poorly it was being used.

SUPPLIERS MEET SPECIFICATIONS

25. After four or five attempts on the part of different suppliers of Albany molding sand, a railroad shipment came through to specification. The other cars were not rejected. Neither we nor the suppliers knew certainly if an Albany sand could be dug to meet these specifications commercially. After the first railroad car to specifications had been received, an order was given to the same company for a barge of 500 tons of the same material, "the test tube grain distribution" of which is shown in Fig. 4.

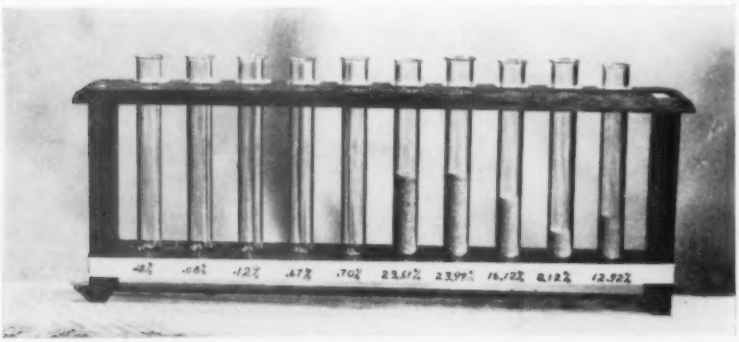

FIG. 4—SCREEN TEST OF ALBANY SAND CONFORMING TO SPECIFICATIONS—A.F.A. CLAY, 13.59 PER CENT; A.F.A. GRAIN FINENESS NUMBER, 139.

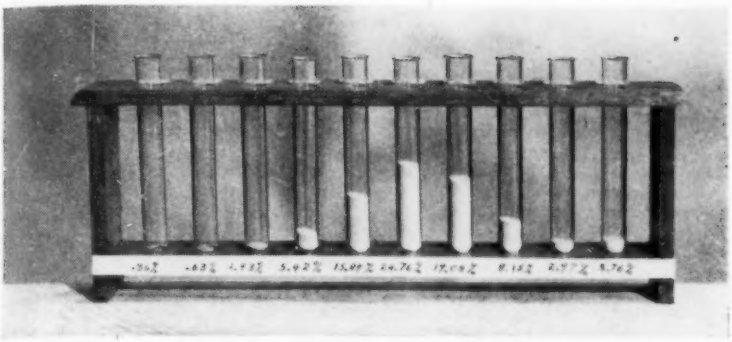

FIG. 5—SCREEN TEST OF COARSE SAND CONFORMING TO SPECIFICATIONS—A.F.A. CLAY, 17.05 PER CENT; A.F.A. GRAIN FINENESS NUMBER, 94.

26. There was still the question of what to do in the case of the heavier castings which needed a sand with still more green compression strength and higher permeability. A natural bonded sand from the New Jersey fields, as is shown in Fig. 5, was chosen which had a much better grain distribution than that coarse sand which had been in use prior to June, 1938.

SAND CONTROL PROGRAM ESTABLISHED

27. All shipments of sand are now tested for A. F. A. clay content, and a screen test is made, saving the samples in the test tube racks for illustrative purposes. Many interesting and instructive discussions have been held concerning grain size and distribution which they so clearly show.

28. The large number of individual molder's sand piles did not seem to be the huge problem of the past. Only four or five different piles are tested each day for moisture, permeability, and green compression strength.

29. These results are kept on cards as is shown in Table 1. If the moisture is considered to be too high, the molder is so informed and his pile tested again each following day until the moisture is found to be under 8 per cent. In the same way, the green compression strength is watched and new sand added if the pile grows too weak.

OBTAINING COOPERATION OF THE MOLDERS

30. The molders did not approve at first of a laboratory man interfering with their sand piles. One of the more intelligent

Table 1

CARD ON WHICH TEST RESULTS ARE ENTERED

SAND-TESTS

Floor No. 30

1939

MOLDER	DATE	MOIST.	PERM.	GR. STR.	REMARKS
62	4/26	5.9	19.0	4.9	
	5/15	6.9	20.0	4.7	
	6/8	7.4	19.5	4.4	
	7/19	8.3	17.5	5.5	WARNED MOLDER
	7/24	7.7	18.0	5.2	
	8/10	7.3	18.5	5.6	
	9/12	7.6	20.0	4.9	
	11/16	7.2	24.0	5.4	
	12/27	7.0	22.0	4.9	
AVER.		7.3	19.8	5.1	
1940	2/8	7.7	21.0	4.2	ADDED NEW SAND

molders was asked to come to the laboratory where he could see the apparatus and the methods used. He was finally convinced that the tests could show him the same things with greater accuracy than could be told by the sense of feel.

SAND TESTS AFTER CHANGES IN PRACTICE

31. After the new Albany sand had been in use for about six months, as additions to the individual piles, they began to closely approach the properties of this new sand. The permeability rose from 12 to 20. The green compression strength from 3.5 to 4.7 lb. per sq. in. The moisture dropped to around 7.0 per cent.

32. There are now a greater number of piles with sufficient permeability for the type of castings being made in them, which consist entirely of the Albany sand. There are only a few piles to which the coarse sand, as is shown in Table 3, is added, and in these piles the permeability varies from 20-30 with a green compression strength of 5.0-7.0 lb. per sq. in.

RESULTS OBTAINED

33. It has been possible to obtain all the benefits of a higher permeability, a higher green compression strength, and a lower

Table 2

SANDS IN MALLEABLE FOUNDRY PRIOR TO JUNE, 1938

Sand	*% On 6 12, 20*	*% On 30*	*% On 40*	*% On 50*	*% On 70*	*% On 100*	*% On 140*	*% On 200*	*% On 270*	*% On Pan*	*A.F.A. Clay %*	*A.F.A. Grain No.*
No. 1 Alb.....	0.20	0.10	0.18	0.28	0.94	3.98	9.94	21.30	17.68	29.70	15.70	199
No. 0 Alb.....	0.14	0.12	0.34	0.38	1.76	14.78	24.62	24.06	13.06	14.00	6.74	147
Coarse	13.58	15.48	18.42	10.22	3.74	6.56	3.24	2.82	2.20	8.46	15.28	68
Heap	3.54	4.56	8.36	10.44	4.26	20.92	11.26	9.14	6.00	10.44	11.08	107

Table 3

SANDS IN MALLEABLE FOUNDRY JUNE, 1939

Sand	*% On 6 12, 20*	*% On 30*	*% On 40*	*% On 50*	*% On 70*	*% On 100*	*% On 140*	*% On 200*	*% On 270*	*% On Pan*	*A.F.A. Clay %*	*A.F.A. Grain No.*
Alb.	0.18	0.08	0.12	0.67	0.70	23.51	23.99	16.12	8.12	12.92	13.59	139
Coarse	0.36	0.63	1.93	5.42	15.89	24.76	19.08	8.15	2.97	3.76	17.05	94

moisture content without sacrificing casting finish. This has been accomplished by the purchase of the sands shown in Table 3 which have a much superior grain distribution than those sands formerly used as shown in Table 2.

DISCUSSION

Presiding: C. C. LAWSON, Wagner Malleable Iron Co., Decatur, Ill.

S. G. FLAGG, JR.[1]: I would like to ask the author whether he does not think the green compression is a little on the low side and also how large is the size of the fittings he makes with that permeability.

MR. SAWTELLE: I think our green compression strength is a little on the low side, though I think it is about the best we can do by buying a natural bonded Albany sand. We never have made any attempt to strengthen it by the addition of bonding materials, as we are not equipped to properly add them. We have always thought that the artificial bonding of sands was a job for a muller. We do that in our steel foundry but we have never gone into it as yet in the malleable foundry.

As far as permeability is concerned, we make up to 6-in. tees without any undue venting of the molds or losses from blowing in sand around 20 permeability. In fact, we used to make them in the first sands shown, which had a permeability of only around 12, though I think the vent rod was used quite a bit.

D. L. DOBSON[2]: I presume you have obtained some benefits from all this work through a reduction of scrap, cleaning, etc. You have not mentioned such benefits.

MR. SAWTELLE: No, I did not mention the fact that you are bound to derive benefits from these changes in figures. A molder can put up more molds with this type of sand. It will cope easier. He will not have the number of blows with the same effort expended. A molder can get sloppy with good sand and perhaps have just as high losses as a molder taking a little more pains with a poorer sand. It is difficult to give accurate figures for reduction of scrap due to changes in sand, as many other conditions are liable to change at the same time.

J. H. LANSING[3]: It would be interesting if Mr. Sawtelle would describe any change with regard to the use of sea coal in their former practice and their present practice.

MR. SAWTELLE: We put the screens to good use one day and made a screen test of our sea coal. Our castings did not have any too good a finish and we found the sea coal was pretty coarse. At that time, we were also experimenting a little with pitch facing compounds, which are

[1] Foundry Superintendent, Stanley G. Flagg Co., Stowe, Pa.
[2] Metallurgical Engineer, General Malleable Corp., Waukesha, Wis.
[3] Shop Practice Engineer, Malleable Founders' Society, Cleveland, O.

extremely fine, and we found that by specifying much finer sea coal on our next order the casting finish was greatly improved.

We have four different facing mixtures which have been used by our foundry superintendent for years. They have not been changed except for the kind of sand that we are now buying for him. The No. 1 facing, as he calls it, which would be used on the lighter castings, has sea coal present in the proportion of 1 to 20. The No. 2 facing, for a little heavier type of castings, has sea coal present in the proportion of 1 to 15. The No. 3, 1 to 12; and the No. 4 facing, 1 to 10, for the larger castings, such as 250-lb. anchors. These facing sands also have a proportion of silica sand added, so the permeabilities are not lowered by the addition of the sea coal. The strength is lowered, but we do not seem to have trouble from that standpoint.

G. PETERSON[4]: Do you use facing on all your castings?

MR. SAWTELLE: No. Nearly 50 per cent of our castings are made without any facing. Perhaps on another 25 per cent, there is a little facing used, but it is just a scattering; it really is not enough to justify calling it a true facing job; and the remaining 25 per cent is faced with sea coal facing material.

G. PETERSON: Do you ever find any checks or small cracks on the surface of especially thin castings that you would lay to the sea coal?

MR. SAWTELLE: Yes, we have proved to our own satisfaction that in the case of thin castings, such as bicycle handle bar stems, that too liberal a use of sea coal in the facing will give us many more checks. In areas where there is likely to be a little shrink, that shrink without sea coal may be entirely under the surface. With sea coal, it will become visible and the castings are rejected just due to surface appearance.

MEMBER: Did the author find any blowholes in the castings when he used a 15 permeability sand?

MR. SAWTELLE: Yes, but not to any large extent. Almost every foundry of our type using the natural bonded molding sands is going to run into blows now and then. The molders can be off on the moisture content, which is more likely to make that happen. They can ram a job much too hard or add too much water, if the strength does not happen to be there, to get that strength. Normally, with a 15 permeability molding sand, without too much water and without too hard ramming, we can make casings weighing 15 lb. apiece without any large loss from blowholes, but they do occur once in a while.

To me, it has always been remarkable how many good castings can be obtained using apparently poor sand, and perhaps the other way around also, how many poor castings can be gotten with what appears to be a very good sand. I think the use of good sand, as measured by testing apparatus, is simply a great help to get good castings. There are many other things which may go wrong. We are now working in the

[4] Foreman, Union Malleable Iron Co., East Moline, Ill.

malleable foundry with natural bonded sand. We intend to mechanize our malleable foundry and one of the molders with whom we are working and trying new synthetic sands said that if he could have that kind of sand, he thought he would be able to put up 150 molds a day instead of 100.

S. HEALY[5]: Would the author explain these cracks caused by sea coal. I understand that excessive sea coal would cause surface checks but I cannot understand how sea coal would accentuate an internal shrink caused by insufficient gating.

MR. SAWTELLE: I do not know as I can explain how that happens, either. With the particular casting on which we are so sure that does occur, the handle bar casting, there is a little shrink at one point where the angle is quite sharp. That shrink has never been large enough to cause the casting to be rejected, except when it extends from the center of the section, which is quite thin, out to the surface so that it can be seen. The castings are given very little finish before they are nickel plated and any surface defects cause rejection, whereas little shrinks where it makes no difference as far as strength goes, are accepted. In that test we did not use sea coal and the percentage of rejects from surface checking was practically nil, whereas with the sea coal, they varied up and down the scale, being as high as 15 per cent one day. The sea coal may not have been the only cause but it certainly aggravated the case.

[5] Assistant to Works Manager, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

The Application of External Chills in the Production of Steel Castings

By W. F. McKee*, East St. Louis, Ill.

Abstract

The proper application of chills to various joined sections of steel castings to control the solidification of the metal, is a point which has received much discussion. In this paper, the author records the results of experiments conducted in the plant with which he is connected, on the proper application of chills to L, T, Y and X sections, where various radii have been used at the section junctions. He has discovered some interesting facts with regard to the placing, cross-sectional area of the chill and the area of contact.

Part I — Advantages and Disadvantages of Various Types of Chills

1. The story of the use of chills is almost as old as the story of iron. We have the story, whether true or legend, of the crude types of chills used by the ancient sword makers. One such story is to the effect that one of the old masters could produce his best swords only if the metal while "soft hot" be cast upon a certain large flat stone. If this had no other effect, it was at least a convenient way of getting the metal into thin sections that would require less hammering to shape into the finished sword.

2. It is said that the maker of the famed "Damascus Sword" upon completing a sword, heated it, and while hot thrust the sword through a "fat slave" and upon withdrawing the blade, if it would not lop off the head of the slave at one blow, the blade was considered inferior and probably required the sacrifice of another "living chill" to bring it up to standard.

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* General Foundry Foreman, The Key Company.

Note: This paper was presented at a session on Steel Castings at the 44th Annual A.F.A. Convention, May 9, 1940, Chicago, Ill.

3. Instances, such as these two crude examples, probably represent the early uses of chills, both in the casting of metals and in the control of grain size after casting. In these two operations, chills continue to play an important role. However, the writer will consider the use of external chills as they are used to dissipate excess heat caused either by design or unequal sections. Due to the higher casting temperature, and composition of metal, cast steel has greater shrinkage than any other cast ferrous metal. This necessitates the use of more chills to correlate the heat loss of unfed heavy sections with that of thinner adjoining sections, through which feeding must sometimes occur.

4. So much has been written about the use of chills, and there is such a store of unpublished information, that one necessarily hesitates to start a discussion of their uses, due to the fact that, to make himself clear, he must do so at the expense of repeating some time-worn and well-known facts.

EXTERNAL VS. INTERNAL CHILLS

5. External chills have some advantages over internal chills. Some of these advantages are:

1. Exact size is not so important. They do not have to fuse into and become a part of the casting metal, as must an internal chill.

2. They can almost always be used more than once. In many cases, they can be used repeatedly.

3. Cleanliness is not of primary importance, as all gases evolved will be at the metal surface and have easy escape through the sand of the mold wall.

4. So far as the writer knows, no user of castings objects to their use, except on sections from which test bars are to be taken. Many users do object to the use of internal chills.

6. External chills have the disadvantage that they nearly always have to be cast, machined or burned to fit the section they are to chill. Size also must receive some consideration, for they must be of sufficient size and shape to chill the intended section, yet not so large or of such shape as to choke off necessary feed, thus causing not only shrinks but cracks. The actual design, in

detail, and location of external chills, is of prime importance as will be shown later, and must be correlated with heading and gating practice to control results.

A Specific Application

7. Perhaps discussion of such a well-known subject as external chills may best be fostered by taking some specific application. The foundry with which the writer is connected, is a specialty shop. Almost all the work is high pressure carbon and alloy castings for the oil industry. They are made under strict specifications and subject to rigid inspection. One of the specifications is that no internal chills may be used in castings, and that no external chills may be used on sections where test bars are to be taken.

8. Fig. 1 shows a few of the many designs of castings used in the oil industry. Although there are myriad designs, they all have section relations that are quite similar and are more clearly illustrated in Fig. 2.

Section Size

9. As-cast, the casting has from $\frac{3}{8}$ to $\frac{1}{2}$-in. more metal for machine finish in tube holes and plug seats, shown in lower part and upper half respectively of both cross section views in Fig. 2. It is readily seen that there is a great different in section between these seats and body metal of casting. This is true especially in crotches between openings in all the many designs, and presents a real problem in proper solidification.

Influencing Directional Solidification

10. The practice in this foundry is to try to influence directional solidification wherever possible. The head and gate are attached to the tube end of the casting. The head sets off the face of the casting adjacent to heavy crotch between openings and the gate feeds directly into the head, so that gate and head are removed with one torch cut. The plug seats are chilled with external chills placed in the mold wall.

Reasons for Use of Chills on Plug Seats

11. It has been found more economical to use chills on plug seats:

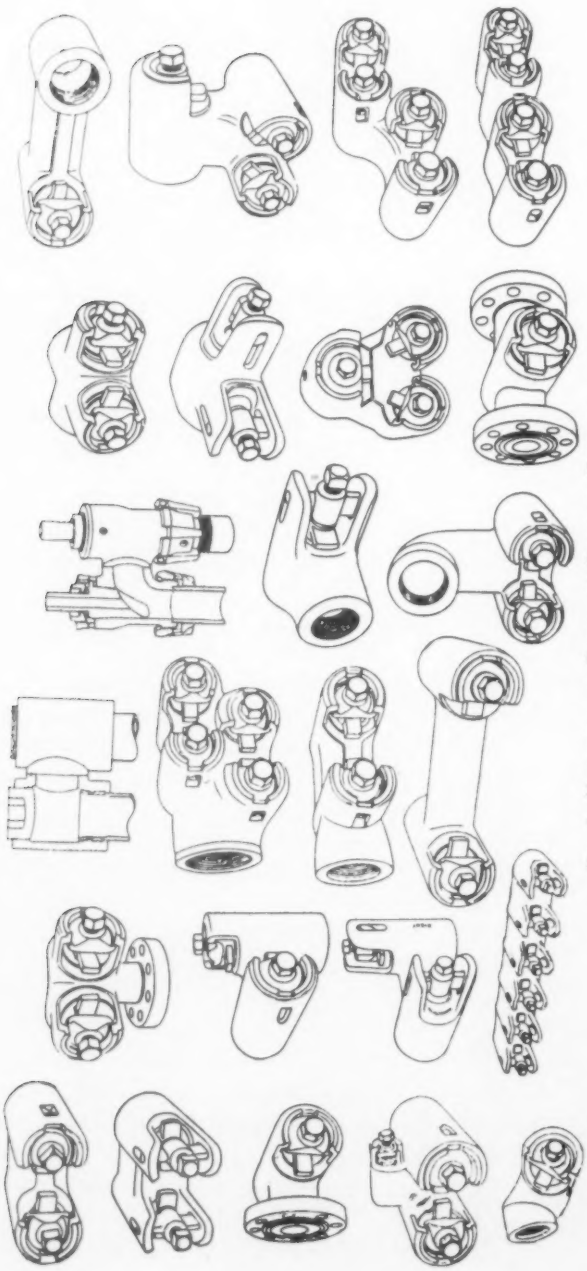

FIG. 1.—VARIATIONS IN DESIGN OF REFINERY FITTINGS.

1. Because of the close nesting tolerances of the castings, it is expensive to remove heads to such close limits.

2. Because the design of casting is such that, to head the casting would mean placing the head in the crotch between the ears, and the removal of the head would be very difficult.

3. Because much of the work is renewals and the chills save much metal that otherwise would be used in heads.

12. Most of these castings are such that plug seats may be made solid with external chills rammed up in mold walls; but an occasional design will have such a heavy section in the crotch that we have to resort to a small chill in the core in addition to usual chills in mold.

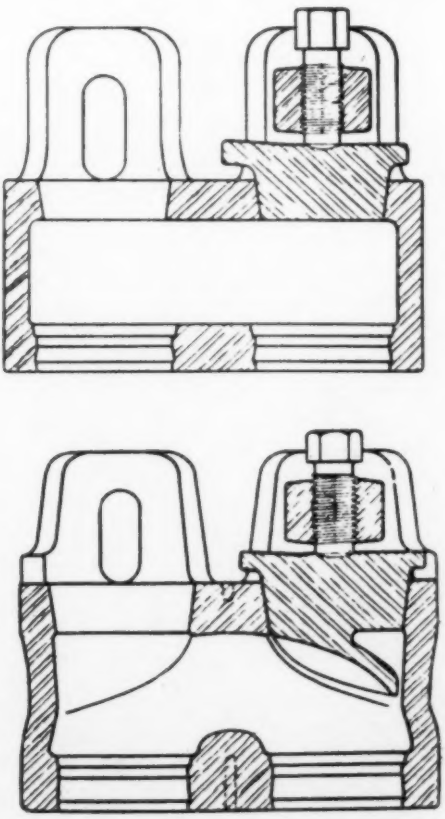

FIG. 2—SECTION RELATIONS OF TYPICAL REFINERY FITTING.

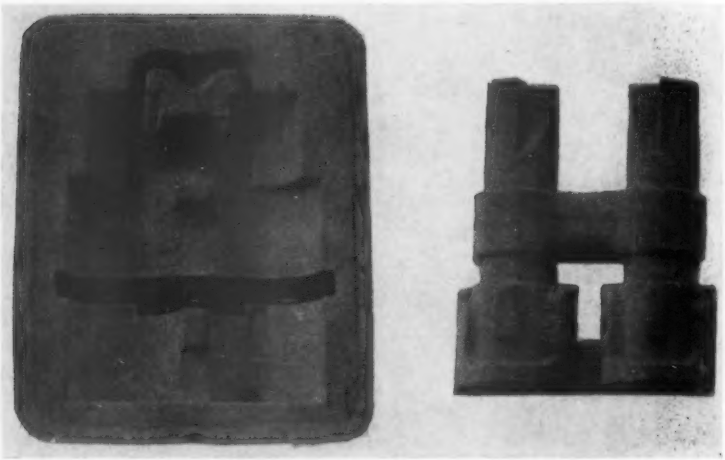

FIG. 3—CORE AND DRAG MOLD FOR REFINERY FITTING WITH CHILLS IN PLACE.

PROCEDURE IN MAKING CASTING

13. Figs. 3 and 4 show the drag and core for such a casting. The chills were painted black so they would be more easily distinguished against the lighter background of core and mold. Normally, the chills in either core or mold get the same spray-wash treatment as the core or mold. They are washed with a silica base mold wash.

14. The cores are dried in a vertical type continuous recirculating oven for 2¾-hr. at 500°F. The molds are dried in horizontal-type, continuous, recirculating oven for 1½-hr. at 600°F. The cope for the drag shown in Fig. 3, would have a like number of chills, thereby making a complete band of chills around the heavier plug-seat section of the casting.

15. The chills in each section of mold are composed of three sections, two band chills and one crotch chill. The section of the chills is determined by an empirical rule developed through experience with this particular class of work. All new designs are determined by the hit-and-miss method and checked by pilot castings.

16. Fig. 4 shows the core set in place in the drag mold. It will be observed that the chills do not cover the edge of seat next to head and gate. This is purposely left open for feeding, otherwise, it would be difficult to get a solid plug seat.

Avoidance of Core Chills

17. Core chills are avoided whenever possible for several reasons:

1. They are more likely to cause defects than outside chills, because, any gas generated does not have as free exit without passing through metal.

2. A greater number is required on long run jobs due to the fact that cores must be made well ahead of casting time, while the mold is made only a few hours, and never more than one day, before being cast.

3. They are more trouble to keep in production, for they often stay in castings until after heat treatment.

4. Due to excess heat and the fact they often go through heat treatment, they deteriorate more rapidly, therefore have to be replaced more often than outside chills.

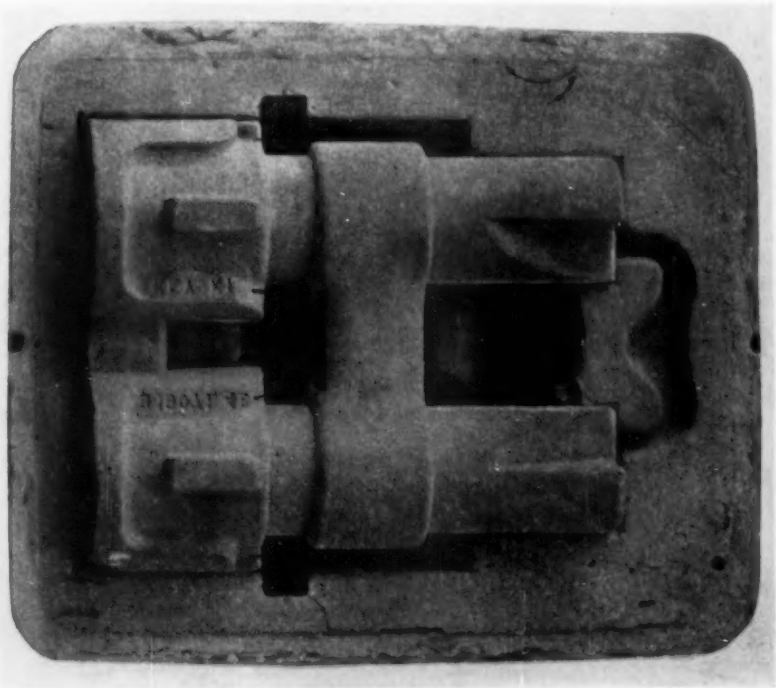

FIG. 4—CORE SET IN PLACE IN DRAG MOLD.

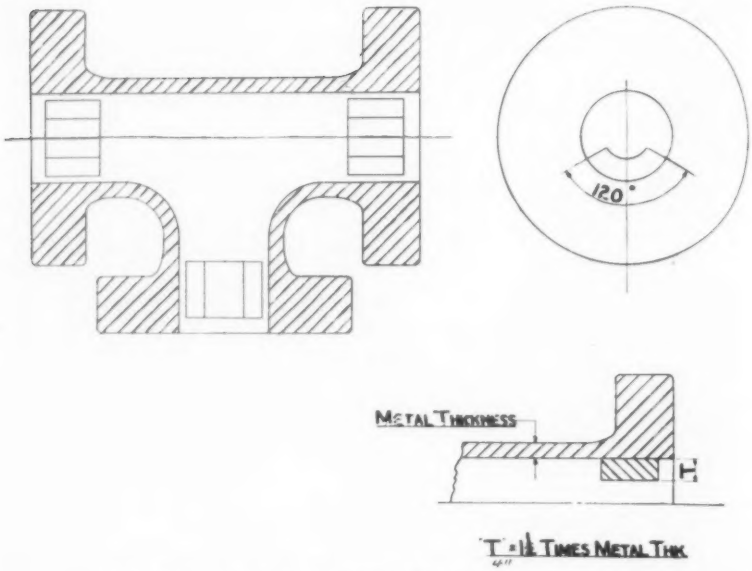

FIG. 5—METHOD OF APPLYING CORE CHILLS TO FLANGED FITTING.

18. This foundry, however, uses core chills extensively in manufacture of flanged fittings. Fig. 5 illustrates this application.

19. These chills are used only in drag half of core, and cover approximately 120° of the inner circle of the flange. The chills must be kept back from the face of the flange, otherwise in casting they may cause small cracks at edge of chill.

Part 2 — Study of Chill Design and Placement of Chills on Section Junctions

20. Some excellent work on design and chilling of section junctions was carried out by Briggs, Gezelius and Donaldson and their results were presented before this association.[1] As these investigators were interested primarily in casting design, the writer was not satisfied with their chill treatment of sections. Since the foundryman is seldom consulted as to the design of castings, a study was instituted to see what results might be accomplished in section junctions with cast chills designed for specific application.

[1] Briggs, C. W., Gezeiius, R. A., and Donaldson, A. R., *"Steel Casting Design for the Engineer and Foundryman,"* TRANSACTIONS, American Foundryman's Association, vol. 46, pp. 605-672 (1938).

Much of the work done in this study follows closely the ideas suggested by a study of the work done by Briggs and his co-workers. Although this present study is far from complete, it is believed the results and information so far obtained may be of interest to some if presented at this time.

Five Ways of Joining Sections

21. There are only five ways in which sections may be joined. These are designated by the letters of the alphabet which a plan view of sections show they most closely resemble namely: *L*, *T*, *V*, *Y* and *X*. There are many modifications of these designs, each of which presents a different problem of solidification.

Patterns Used

22. The patterns used were of 3 x 3-in. cross-section. The arms were 18-in. long, with heads attached at extreme ends. Molding was by the green sand method, and chills were uncoated. All castings were poured in the horizontal position through feed heads. Plain-carbon, acid-electric steel was used. The steel was poured from a bottom pour ladle, with the metal taken from near the middle of a 4-ton heat. To avoid erroneous results, produced by the effects of directional solidification and temperature gradients, all castings of a series were poured consecutively in the same heat and through corresponding feed heads.

Reasons for Use of 3-in. Sections

23. Castings with 3-in. sections were used in these studies because:

1. A large section would produce more pronounced defects.

2. The temperature of metal and condition of molding sand would not influence the results in a heavy section so much as in a lighter one.

3. Sections this large are not uncommon in heavy machine and structural castings, and are sometimes isolated in castings where it is not practical to feed except through the arms.

4. It is believed the information obtained from chilling these sections may be applied to either heavier or lighter sections with corresponding results.

24. The effect upon solidification, caused by the use of different radii at the junctions, was studied and chills were designed to meet the different problems. Cast chills were used in all applications. Some of the chill treatments given these sections were novel, and had varying degrees of success, all of which will be noted later in discussing the results.

Etching Treatment

25. The castings for illustrations used in this discussion, were prepared by removing the arms a short distance from section junctions. The junctions were then burned through center, plan view, ground and etched for 20-min. in boiling 1 to 4 sulfuric acid solution. This treatment is believed sufficient to make all harmful defects visible.

DISCUSSION OF RESULTS

26. For the purpose of this discussion, consider these sections as located in casting in such a manner that it is impossible to feed except through arms. They may be considered of indefinite length. The chills of course would be of corresponding length. The depth of section, theoretically, will make no difference in size and location in plan view of defect.

27. The chills also will be considered in plan view, and volume will not be considered for it would be as indefinite as the length of chill. All chills used on a casting were measured and the surface in contact with casting wall will hereafter be described as "contact surface." The combined area of all chills used on each casting will also be given. For ease of comparing effect of chills, one casting in each series was made without chills and will be shown as No. 1 casting in each group.

"L" Section

28. The "L" is the most common and most used of all junctions. Fortunately, it is also easiest of all junctions to make solid by the use of chills.

29. *One-in. Radii.* Fig. 6 shows "L" sections with 1-in. radii used in inside corners. Fig. 6-2 shows a casting with crotch chill covering the entire radius. The casting shows no defect. The contact surface was 1.6-in., the chill area 0.67 sq. in. Fig. 6-3 was

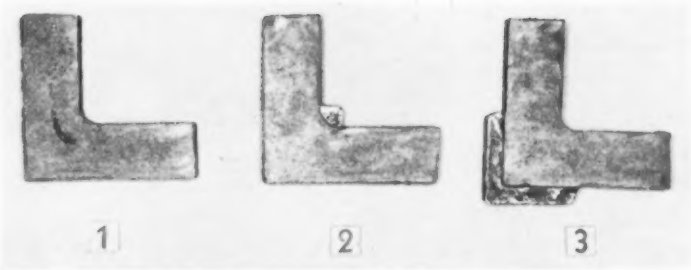

Fig. 6—Chill Treatment of "L" Sections with 1-in. Radii.

cast with a saddle-chill around the outside corner. The casting is sound. The contact surface is 7.5 in., the chill area 6.8 sq. in. This is believed to be the better of the two chill applications because:

1. It is the simplest chill to make to fit the surface.

2. So long as the chill does not extend too far out on the arms of casting, over-chilling cannot be produced, as is so easily the case with crotch chills, which will be shown in a later application.

3. It is well known that if the outside corner of an "L" section be broken by a radius that will cause the section to be slightly smaller at the junction than the arms, the section may be cast solid. This saddle chill acts directly upon the section that would thus be removed and allows arms to feed the section while solidification occurs.

30. *Two-in. Radii.* Chill treatment of "L" sections with 2-in. radii are shown in Fig. 7.

31. The specimen of Fig. 7-2 was cast with a chill covering the entire inner radius. This was definitely too large or of improper design for the casting has a defect one-half as large as in Fig. 7-1. The contact surface was 3.25-in., the chill area 3.7 sq. in. Fig. 7-3 shows a chill that covered approximately three-fourths of the radius. Each edge of the chill is one-eighth of the radius removed from the tangent point, allowing arms to remain open and feed the section being chilled. The casting is solid. The contact surface is 2.25-in., the chill area is 2.9 sq. in. The chill is definitely smaller than that of Fig. 7-2, although it produced a sound casting. The saddle-chill was used on the specimen of Fig. 7-4 and pro-

duced a sound casting, although the chill was the same size as one used on the section with 1-in. radius. The contact surface is 7.5-in., the chill area 6.8 sq. in.

32. *Three-in. Radii.* Sections of "L" shape with 3-in. radii are shown in Fig. 8. Here again (Fig. 8-2) the crotch chill that covers entire inner radius failed to produce a sound casting because it caused the arms to freeze before the heavy sections could become solid. The surface contact is 4.5-in., the chill area 6.0 sq. in.

33. A chill that covers three-fourths of inner radius was used on the specimen of Fig. 8-3. It produced a commercially sound casting, although there is a minor "spongy" area near center of heavy section. The contact surface is 2.6-in., the chill area 4.1 sq. in.

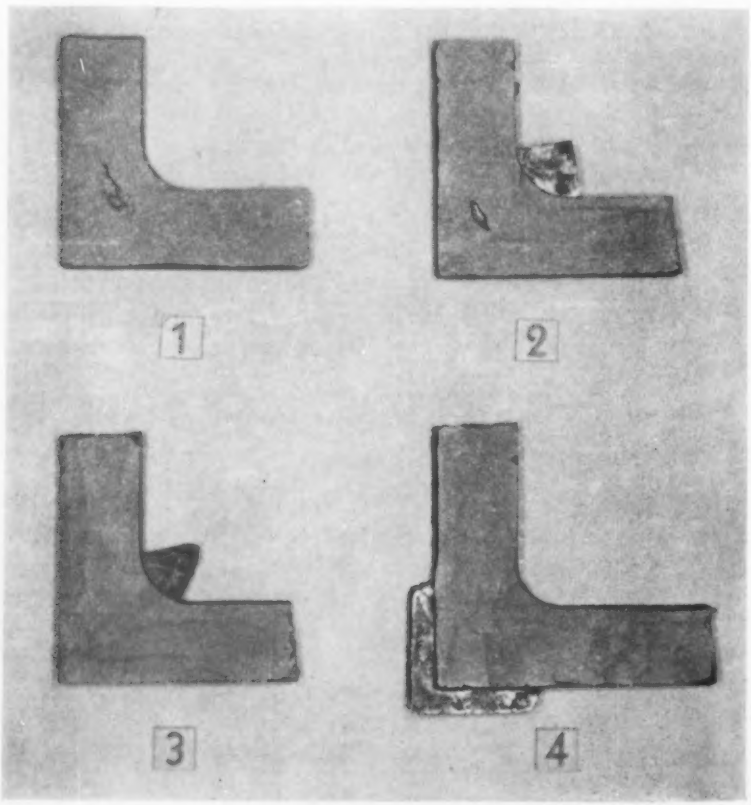

FIG. 7—CHILL TREATMENT OF "L" SECTIONS WITH 2-IN. RADII.

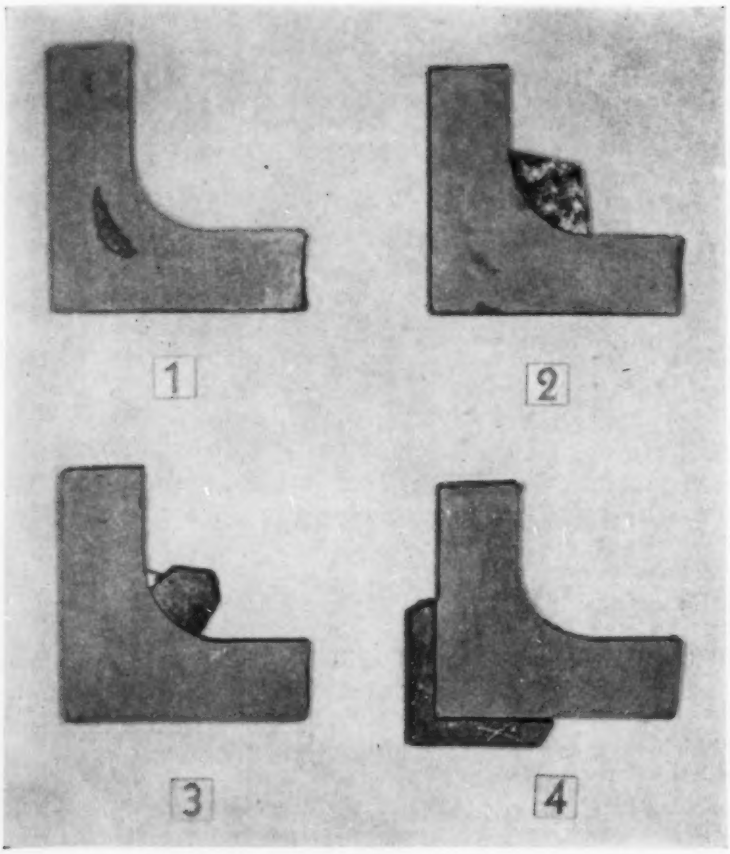

Fig. 8—Chill Treatment of "L" Sections with 3-in. Radii.

34. A saddle-chill was used on the specimen of Fig. 8-4 producing a sound casting. It will be noted this chill covers the outside wall of casting from a point opposite the tangent points of inner radius. This is, the writer believes, the proper area to be covered by a chill of this type. The contact surface is 9.0 in., the chill area 9.2 sq. in.

"T" Sections

35. *One-in. Radii.* Fig. 9 shows chills used on "T" sections with 1-in. radii. Fig. 9-2 shows what may be considered as the conventional way of chilling such sections. The chills consist of two chills that cover the entire radius placed in the corners and large flat chill placed across the top of the "T." This casting is

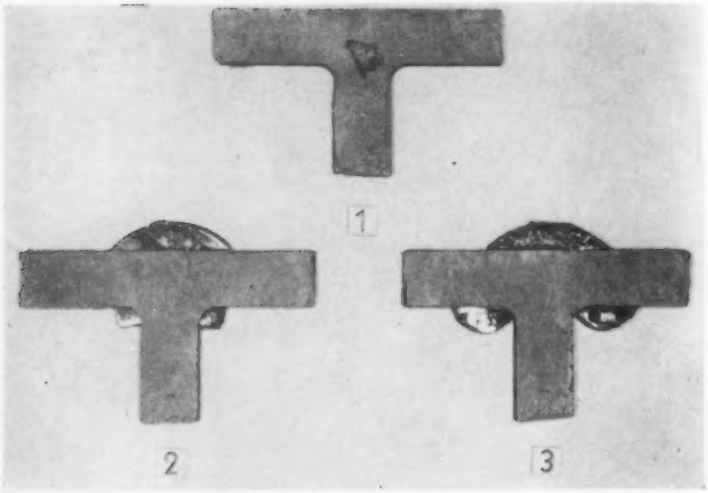

FIG. 9—CHILL TREATMENT OF "T" SECTIONS WITH 1-IN. RADII.

commercially sound although there is a very slight "spongy" section almost between crotch chills. The contact surface is 9.25 in., the chill area 7.9 sq. in.

36. In Fig. 9-3 the crotch chills are placed more on the arms and cover about three-fourths of the radii. This was done to try

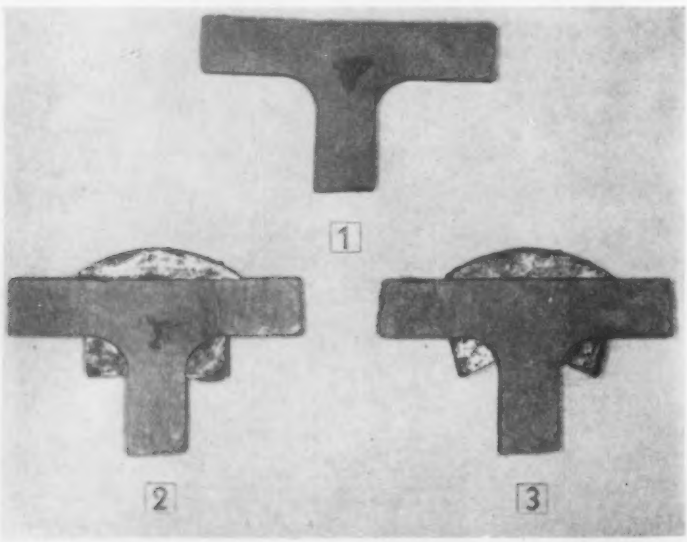

FIG. 10—CHILL TREATMENT OF "T" SECTIONS WITH 2-IN RADII.

to avoid freezing the leg so that the chilled section would be fed through the leg. The casting is solid. The contact surface is 12.75 in., the chill area 11.8 sq. in.

37. *Two-in. Radii.* Sections of "T" shape with 2-in. radii are shown in Fig. 10. Section 10-2 was chilled with conventional chills that covered entire radii at the leg junction together with a large chill across the top of the "T." The defect found is almost as large as in unchilled specimen, due, it is believed, to the fact that size and location of chills caused the arms to freeze and shut off all feed. The contact surface is 15.25 in., the chill area 12.9 sq. in.

38. Section 10-3 was chilled with crotch chills that covered the radii from tangent point on the arms, three-fourths distance to the tangent points on the leg. It will be noted these chills were designed to have sharp re-entrant angle of sand between chills and the wall of the leg. This helped to dampen the effect of the chill upon the leg and allowed it to feed necessary metal to the larger section. The large chill was also used across the top of the "T." The section is sound. The contact surface is 14.25 in., the chill area 11.9 sq. in.

39. *Three-in. Radii.* Fig. 11 shows "T" sections with 3-in. radii. This section is extremely hard to cast sound. Such large radii form sections at the junction so heavy that abnormally large chills must be resorted to in order to chill this excess metal.

40. Conventional chills used on Fig. 11-2 did not produce a sound casting. The defect is approximately one-half as large as in the un-chilled specimen. Contact surface is 18.25 in., the chill area 17.9 sq. in.

41. Heavy chills, acting mostly upon arms and covering approximately three-fourths of radii on the leg, together with chill across the top of the "T," produced the sound casting in Fig. 11-3. The contact surface is 18.75 in., the chill area 25.0 sq. in.

"Y" Sections

42. Sections of "Y" shape with 3-in. radii in the crotch presents a rather heavy section to be chilled, however it is not as difficult to chill these successfully as "T" sections with large radii, because chills may be placed more in direct contact with the section to be chilled.

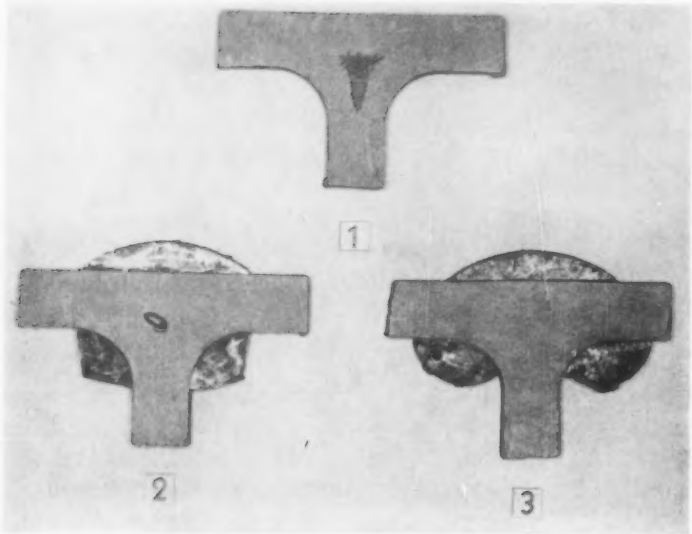

FIG. 11—CHILL TREATMENT OF "T" SECTIONS WITH 3-IN. RADII.

43. Fig. 12 illustrates the results of some attempts to chill such a section. The specimen of Fig. 12-2 was cast with a crotch chill covering the entire crotch radius, also with large chills covering the entire wall of the casting adjacent to the heavy section and extending over the entire radii at the junction with the leg. The defect, while small was critical, proving to be a complete cavity. The contact surface is 15.25 in., the chill area 19.0 sq. in.

44. The same size and shape crotch-chill was used on the specimen of Fig. 12-3 as was used on Fig. 12-2, but plate chills were used on the sides of the heavy section. It will be noted they do not extend down to the leg junction. A small defect appears directly between the ends of chills, just above the junction with the leg. The contact surface is 13.25 in., the chill area 12.9 sq. in.

45. Exactly the same chills were used on Fig. 12-4, but plate chills were placed almost down to the leg junction. The location of the chills is most important. The casting was sound. The contact surface is 13.25 in., the chill area 12.9 sq. in.

46. Should the design of the "Y" be changed as demonstrated in Fig. 13, it becomes a much more simple section to chill. The crotch retains the 3 in. radius, but the sides that were straight

are now curved inward, eliminating much of the metal that formed the junction of the design of Fig. 12.

47. A crotch-chill, covering the entire radius, together with side-chills that cover the casting wall from point opposite tangent point of crotch radius to tangent point of radii on the leg were used on the specimen of Fig. 13-2. The defect was small but it was a clear cavity. The surface contact is 14.75 in., the chill area 15.2 sq. in.

48. The same chills were used on the specimen of Fig. 13-3 as those used on Fig. 13-2, except that the ends of outside chills,

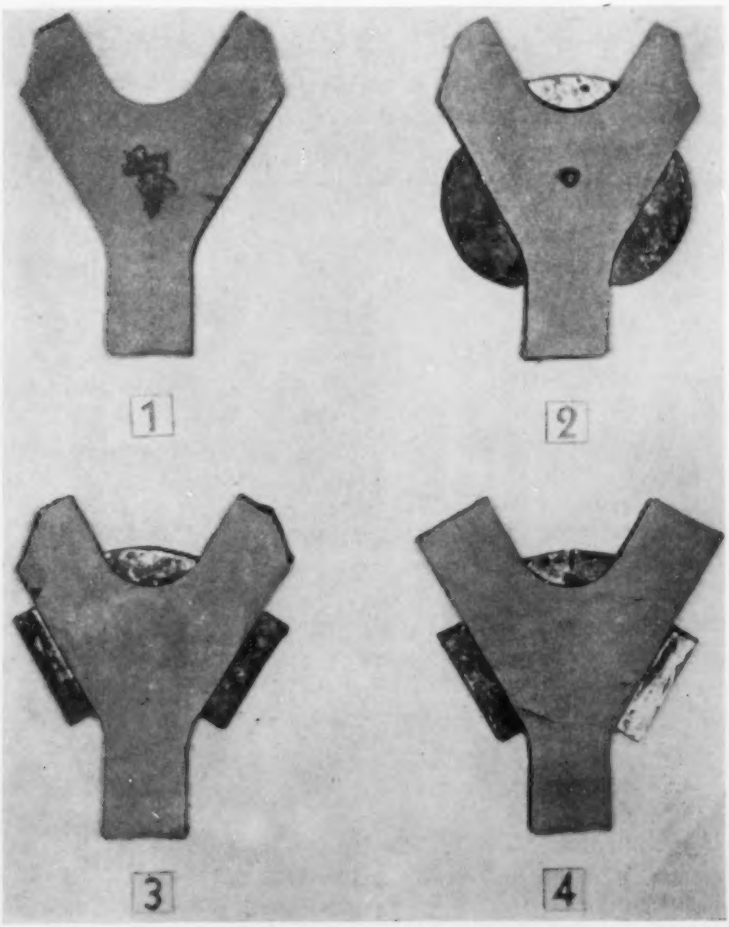

Fig. 12—Chill Treatment of "Y" Section with 3-in. Crotch Radii.

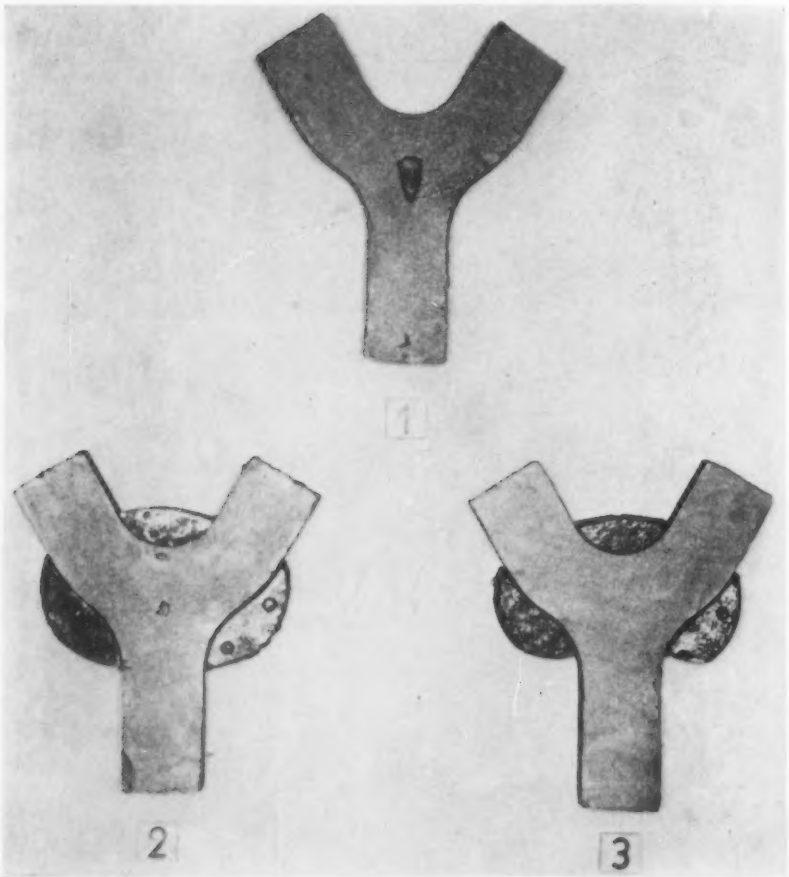

FIG. 13—CHILL TREATMENT OF RE-DESIGNED "Y" SECTIONS.

that covered the radii at the leg junction, were removed so that the chills covered about one-half of the radii. The casting produced was sound. The contact surface is 12.75 in., the chill area 13.5 sq. in.

"X" Sections

49. The cross is perhaps the most difficult of all sections to cast solid without feeding direct. The junction of four sections of metal in this form causes the largest possible section of metal exposed to the least amount of mold wall through which the heat may be dissipated. Chilling is made difficult for the same reason,

not enough chill surface may be exposed to heavy section created by the junctions without freezing off arms and preventing feed.

50. *One-in. Radii.* Chill treatment of "X" sections with 1-in. radii is illustrated in Fig. 14. Chills, that may be considered conventional, were used on the specimen of Fig. 14-2. They covered the entire radii. The defect was a complete cavity. The contact surface is 6.0 in., the chill area 4.1 sq. in.

51. On the specimen of Fig. 14-3, an attempt was made to chill the junctions of arms *A* and *C* completely and allow junctions of arms *B* and *D* to solidify as a straight section. The chills covered one-half of radii and there was a very acute angle of sand between the chills and arms *B* and *D*. The results might have been more gratifying if this "hot spot" of sand could have been eliminated. The casting was commercially sound, for it will be noted the defect is no more severe than the center-line weakness visible under letter on arm *B*. The contact surface is 11.25 in., the chill area 14.1 sq. in.

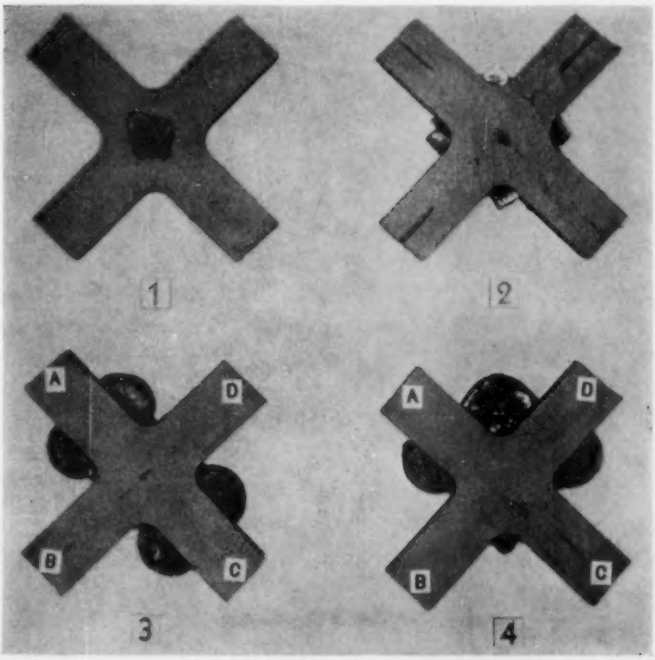

Fig. 14—Chill Treatment of "X" Sections with 1-in. Radii.

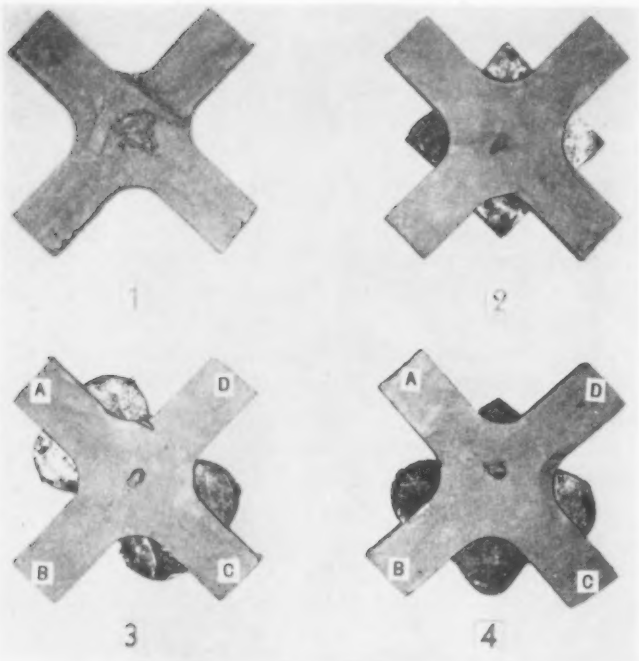

FIG. 15—CHILL TREATMENT OF "X" SECTIONS WITH 2-IN. RADII.

52. From a study of the results achieved in this casting, it seemed desirable to get more chill surface in contact with the heavy metal section and this was attempted in Fig. 14-4. Here the desire was to chill junctions *A* and *D* completely and treat *B* and *C* as an "L" section. The same type chill, as used on Fig. 14-2, was placed on the outside of arms *A* and *D* at their junction, and a large chill was placed between the arms. A conventional radius chill was placed between arms *B* and *C*. The casting had no cavity although a "spongy" area developed between junctions *B* and *C*. It was not serious for it may be seen that it is not as large as center-line weakness in arm *C*. The contact surface is 17.25 in., the chill area 17.2 sq. in.

53. As the radii at junctions of the arms of "X" are increased the possibility of a sound casting without the use of direct feed becomes more impracticable.

54. *Two-in. Radii.* In Fig. 15, the "X" sections have 2-in. radii. The same chilling effect was applied as in Fig. 14, only with

larger chills designed to fit the larger sections. The results were not at all satisfactory. It appears the section created by these junctions is so large it is not possible to apply sufficient external chills and keep the arms open to feed the section until it becomes solid. For Fig. 15-2, the contact surface is 12.25 in., the chill area 14.0 sq. in. For Fig. 15-3, the contact surface is 15.0 in., the chill area 19.2 sq. in. For Fig. 15-4, the contact surface is 16.0 in., the chill area 19.1 sq. in.

55. It will be seen that these chills are so large as to be difficult to hold in place either in the mold wall or in the core.

56. *Three-in. Radii.* Fig. 16 shows the "X" section with 3-in. radii. Here again is demonstrated the impracticability of chilling a section such as this with external chills alone. The chills used are almost equal in volume to the casting, but the casting still has serious defects. For Fig. 16-2, the contact surface is 18.0 in., the chill area 23.7 sq. in. For Fig. 16-3, the contact surface is 17.75 in., the chill area 24.3 sq. in.

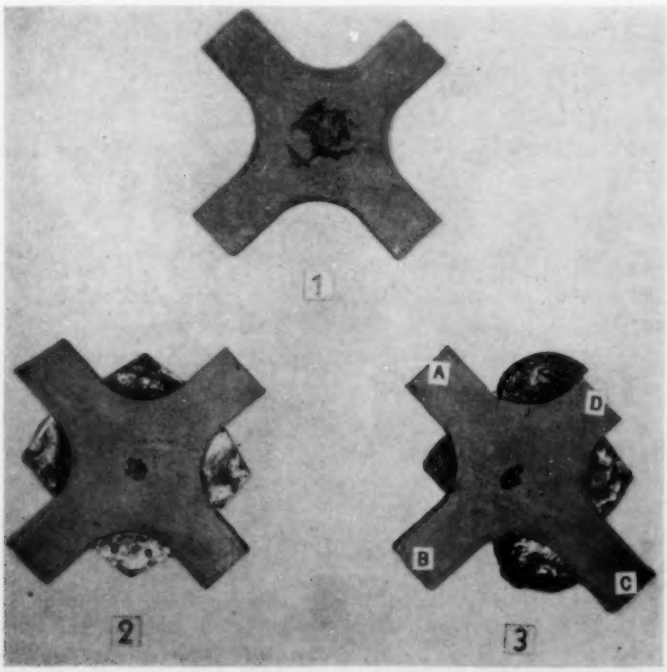

Fig. 16—Chill Treatment of "X" Sections with 3-in. Radii.

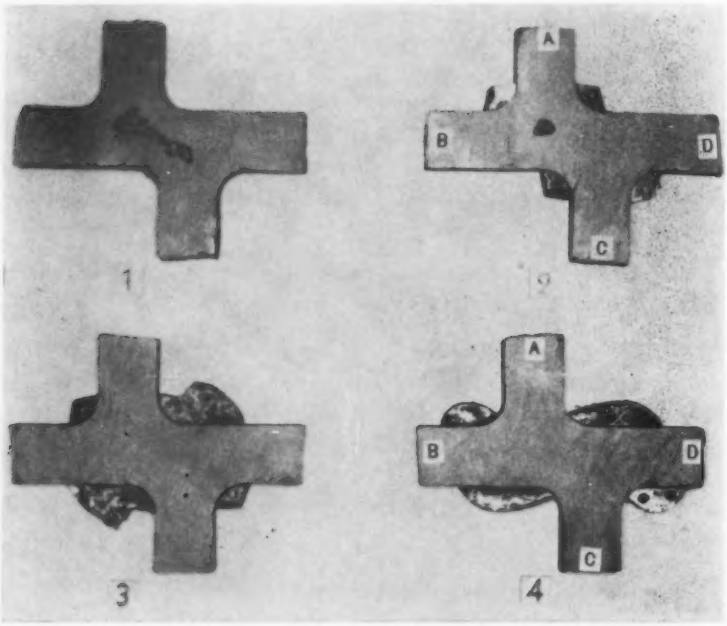

FIG. 17—CHILL TREATMENT OF STAGGERED "X" SECTION WITH 1½-IN. RADII.

57. If the design of the "X" can be changed and the arms staggered as much as the thickness of the arms, the problem of producing a sound casting is made more simple.

Staggered Cross-Members

58. Fig. 17 shows a staggered "X" with 1½-in. radii and the chill treatment necessary to produce a sound casting. Fig. 17-2 has small chills covering the radii. There is a definite shrink at the junction of arms *A* and *B*, while the junction of arms *C* and *D* is sound. Both sections had the same amount of chills. The only reason advanced as to why one section is solid and the other is not, is temperature gradient. The casting was probably poured through either arm *A* or *B*, and their junction became more heated than the junction of *C* and *D*. The contact surface is 9.0 in., the chill area 5.8 sq. in.

59. Fig. 17-3 shows what may be considered a conventional way of chilling this section. It is chilled much like a "T" section. Small chills cover the entire radii at the junction of the legs, with larger chills covering opposite radii and side of the arms opposite

the junction of the legs. The casting shows small defects at the leg junctions. The contact surface is 15.0 in., the chill area 15.4 sq. in.

60. The specimen of Fig. 17-4 is chilled much in the same way as it was found necessary to chill "T" sections with larger radii. The chills cover about one-half of the radii and legs *A* and *C* are left open to feed the sections being chilled. The casting is sound. The contact surface is 16.5 in., the chill area 15.0 sq. in.

Conclusions

61. From the results obtained in this study the following conclusions are reached:

1. Chill design is as important as size.
2. Chills should never be designed so as to form re-entrant angles of sand at their sides or ends, except where it is desired to retard or control the chilling effect.
3. Placing of chills is important, and requires study.
4. Where chills are to be used on section junctions, it is desirable to have the radii at least one-third as great as the section thickness, but never more than one-half as great.

Acknowledgments

62. The author wishes to express his appreciation to A. C. Skelton[2] for patterns used in this study and to Robert H. Jacoby[3] for the photography.

[2, 3] Pattern foreman and assistant metallurgist, respectively, Key Company.

DISCUSSION

Presiding: H. M. Rishel, American Steel Foundries, Granite City, Ill.

T. D. West[1] *(Written Discussion):* The subject, the application of external chills in the production of steel castings, will be forever an interesting one. The non-destructive tests which are being used more and more bring out the superiority of wisely placed external chills over internal chills. However today the regular commercial casting has its share of internal chills and will continue to do so until the financial return warrants the extreme careful diagnosis of the casting from the standpoint of design, directional solidification and contraction.

The writer makes the following statement in paragraph 5 on the

[1] Foundry Superintendent, Symington Gould Corp., Rochester, N. Y.

subject of external chills: "Cleanliness is not of primary importance, as all gases evolved will be at the metal surface and have an easy escape through the sand of the mold wall." The author does not express the degree of cleanliness at which the chill has to be held, but experience has shown that the external chill has to be clean of any iron oxide or sand inclusions. We, in our plant, shot blast all external chills followed by tumbling to smooth them off. Some of these chills are then coated with a special preparation and others, where they do not fuse, are used with no coating at all.

The author in describing the placing of external chills in Fig. 3 states that similar chills are placed in cope. Does the author ever have any trouble from external cope chills such as blows or accumulation of gas? The writer will not use any cope chills as he has had the above mentioned trouble. The chills used on this fitting are sectioned. What amount of sand does the author prefer to have between chills?

The author's method of applying internal chill on flanged fittings is a novel one in the writer's opinion. However, he states that the chill must be kept back from the edge to avoid cracks. Evidently, the author has had trouble from the chilling effect causing a crack, and instead of tapering off the chill to an edge, they have moved the chill in from the edge and perhaps are still getting the crack, but fluid metal is filling it before the flange solidifies.

The author states that in making the shrinkage tests on joining sections, the molds were poured from a bottom pour ladle near the middle of the heat. No temperature was recorded in any way. The writer has yet to find heat after heat at exactly the same temperature regardless of how it is made, controlled or poured. For each 100° superheat of *molten* steel there is an increase of approximately 1 per cent of liquid contraction. Certainly this factor would vary the test results. Another variance that would come into these tests is the question whether the pouring gate was kept open longer by using riser dust, thus letting atmospheric and hydrostatic pressure vary the tests. This last item is very important as castings can be fed up-hill provided the riser is kept open longer than the casting takes to solidify.

Has the author used cast steel chills on all applications of these tests? The writer would like to know if it is possible to use cast iron, or malleable, to an advantage where the chill does not fuse to the casting.

The author does not give any set length for chills on his sections. How long are these chills and what amount of sand is rammed up in between them? The writer has experienced cracking between chills and has had to resort to other external chills on the opposite side to overlap the space.

The author states that the saddle chill used on Fig. 7-4 was the same as used on Fig. 6-3. Then was it not true that 6-3 was overchilled?

The reason for chilling, in the writer's mind, is to tend to reduce unevenness of section thus promoting directional solidification and soundness of castings.

MR. MCKEE: With regard to my statement that cleanliness is not of primary importance, by that I meant cleanliness as applied to external chills. I suppose that everyone has had the sad experience of using an internal chill and finding that even the perspiration of the molder's fingers, where he placed them while working, caused the chill to rust and caused bubbles and blow holes in the sections. External chills are not that delicate, although they should be kept reasonably clean. They do not have to be kept as clean as internal chills. A small amount of oxide would not cause more than a mere bubble at the metal surface. We clean our chills.

We have very little trouble with gas caused from the cope chills. I think they cause no more trouble than the dry chills. Naturally the surface is a little rougher under chills in every case than it would be where it flows against the sand but it is not particularly objectionable.

I do not think we get cracks from the application of chills on flange fittings. We have to test them carefully. If the chills are too close to the edge it is too easy to start a crack from the sharp edge of the metal, that is, the flange edge.

We check the temperature on almost every heat poured, we check several heats every day, at least, and we have fairly constant temperatures. We tap and pour from 2850 to 2890°F. If you have a heat that is 100° hotter than the previous heat and you have found that certain chill sections will take care of a given hot spot or heavier section, the extra temperature of that heat will cause the sections through which those chills have to draw feed-metal for the heavy section to remain liquid much longer. In the speaker's opinion, they will be as much longer in setting as it will take those chills to dissipate that excess heat from the heavy section. So I do not think that would make much difference.

I did use cast steel chills in every application. In the case of gray iron chills and malleable chills, it has been our experience that they distort more readily than steel chills of proper design. They fuse in more too, because they have a lower melting point.

In regard to the saddle chill, I do not think, so long as cracks are not produced by over-chilling, that section showing in Fig. 6-3 would be over-chilled with the saddle chill outside, around the corner, because it would be chilling from the corner inward, and, as long as the chill does not extend too far out over the arms of the section, over-chilling would not result with that type of over-chill.

CHAIRMAN RISHEL: I had some experience a few years ago using gray iron chills in certain places. The question was, would the gray

iron chill fuse? In our case it did melt and we had a decided blowing underneath the external chill.

I believe that part of Mr. West's question referred to the amount of sand left between chills. He was also afraid of too large an area being chilled or too long a chill being used.

MR. MCKEE: On our standard cope and drag chill practice, we strive to keep them as close together as possible with no sand between. In fact, they are cast to fit at the ends, so there will be no sand between them. A slight clearance has to be left where the cope and drag join at the parting line to keep the chills from pushing out of place on the mold. There is never enough to cause more than a slight fin, and seldom ever fin runs, between the chills.

T. D. WEST: Would your fin produce a crack to any extent?

MR. MCKEE: They do not seem to. If we leave the chills open where they join onto the crotch chill we do sometimes have cracks if the chills do not fit properly. It has not been our experience that we have ever had cracks at the parting lines where the chills join.

There is just one other thing I would like to add about the use of malleable or cast iron chills. I doubt if we could use them on the high alloys that we have to cast. I think there might be some reaction there. I believe there are cases on record where they did produce local hard spots.

CHAIRMAN RISHEL: Mr. West had a question as to whether you were able to put this chill through the entire 18-in. length without the danger of getting cracks.

MR. MCKEE: I did not have any trouble by using them that way. On the patterns, the arms were 3-in. square and 18-in. long. The idea being that with a section such as this, on any kind of heavy casting where it could not be headed, this same chill laid the entire length certainly should produce the same results because the depth of section that way would not change the area of the junctions as we study them here. So the chill would naturally be as long as the section itself. However, in my case they were three inches long. They just reached the depth of the casting.

MEMBER: How about the contraction and expansion of the chills?

MR. MCKEE: We have contraction around the circumference of our castings and yet if the chills are properly placed we do not have cracks. So there would be no more than that certainly, unless we had quite a long section.

CHAIRMAN RISHEL: That last statement cleared up something in my mind because I had pictured that these chills ran the entire 18-in. length. Now it is brought out they were only 3-in. long.

MR. MCKEE: The author did not try to justify these larger radii. I merely tried to show the impracticability of them. I agree that the radii should be kept as small as possible. Perhaps the designing engineers do permit them to change the design. I merely wanted to find out what we could do if we had to, and I admit it is impracticable, although with enough chill application it can be done.

As to the best method of finding the soundness of the section, unquestionably radiography is the answer. However, we, especially on the heavier radii, seemed to be sound there, with a good many tests made to see if it was characteristic. We might have missed the defects in our grinding. I do not know of any way we could help it because we were not equipped for testing with radiography.

CHAIRMAN RISHEL: I was very glad to see this emphasis put on design. I think a lot can be done, and certainly nowhere near enough has been done, in the past, towards our problem being studied, as to how the design can be corrected so as to make it an easier foundry job. However, for years past the foundryman has been presented with a problem of what he was going to do with the thing that he had to make, where there was no chance for a change in design. Mr. McKee's object in tackling that problem with these designs and his conclusions, that the 3-in. radii is impracticable to solve from the standpoint of external chilling, is very sound and logical. I think that Mr. West and Mr. McKee are merely approaching it with emphasis on a little different angle and that both are right.

One angle that has not been discussed very much is the matter of tapering a chill so as to get away from the tendency to crack. My experience certainly leads me to believe that external chills have to be handled very carefully from the standpoint of design, weight of chills and taper at the end of the chill to prevent cracking.

R. A. GEZELIUS[2]: Papers of this type are of no value if the foundryman forgets that the degree of superheat and the amount of steel which passes over the chill will change the chilling effect. Any one of you can prove that nicely in your own foundry by making a series of castings shaped like a common brick. It does not make any difference what the dimensions are. Three sides of the bricks should be cast against sand and the fourth side chilled. If these castings are emptied at intervals, you will note at the very beginning there is a decided difference in thickness, that is, the chilling action is very pronounced. As time goes on, however, that difference remains constant. In other words, the chill can soak up just so much heat. From that point on it has to radiate the heat through the sand. If enough metal goes over a chill so that it is heated up before the casting starts to solidify, it is of absolutely no value.

CHAIRMAN RISHEL: In some work that was done in the St. Louis area on chills to try to arrive at the correct weight of chills for chilling

[2] Metallurgical Engineer, General Steel Castings Corp., Eddystone, Pa.

of intersecting sections, it was found that a section might be cut with a saw at one place showing solid metal, and a half inch from there a very decided defect would be found.

K. V. WHEELER[3]: One question about chills that has been bothering me is a cheap and easy way to make the patterns for irregular shaped external chills. It is true that standard shapes, half-round, or quarter-round, or full-round, can be purchased or made. But have we not a problem in the use of external chills in the making of the patterns, which is always so expensive?

I would like to state an experience we have had in using external chills regarding the effect of the expansion of the chill if it is too long. To illustrate that, we have used chills straight, or irregular shaped of, we will say, 12 to 14-in. in length in the fillet where a flange joins the body of a casting. We found if that chill were of, what we thought, the proper thickness to give the chilling effect, it would expand rapidly when the metal is poured into the mold. Could the author give us a few comments on the relation of the length of chill to the thickness of chill that is safe to use?

MR. MCKEE: Unfortunately, Mr. Wheeler, I do not have the answer to your question on the relation of thickness to length. I had some experience with trying to chill a section on a plate casting. The plate was approximately 7-ft. long and had a rib or set of ribs, and there was no way to feed it except chilling. I tried to chill it using one long chill with sad results. We had to cut the chill to about a 10-in. length. We had to be very careful that the ends of the chills would fit each other carefuly so there would be no fin in between because that would cause cracks.

CHAIRMAN RISHEL: One point that Mr. Wheeler raised was, how can you produce a very crooked design chill for a particular part cheaply? Has anyone the answer to that?

W. N. HATFIELD[4]: Mr. Wheeler's problem may be solved by making the pattern as usual, then fastening on by screws an added wood block the shape of the cast chill, using this wood block as a pattern. If any alterations are desired which is many times the case, the block may be taken off and whittled a little bit in order to alter the shape until a casting is also secured which is sound. This method is extensively used for shaping risers.

A. H. MARKWORTH[5]: We have quite frequently had occasion to chill various irregular sections. We make a plaster pattern to produce cheap cast to shape chills. We pour it around the section to be chilled and after it sets it is trimmed and shaped to what we think is the proper cross section required to chill the particular section. The plaster pattern is then taken to an aluminum foundry which in turn makes white metal patterns which are then gated. This gate and pattern assembly

[3] Vice-President, American Steel Castings Co., Newark, N. J.
[4] Electric Steel Castings Co., Speedway, Ind.
[5] Foreman, Patterns, American Steel Foundries, Granite City; Ill.

are molded and the necessary parting made. Before pouring, the cope and drag flasks are separated approximately ½-in. which gives us the plate thickness, with the cope chill pattern on one side of plate and the drag on the other. We have had as many as 60 patterns on one plate, of course depending on the size and shape of chill required. This gives us a fairly cheap chill pattern plate and also keeps the cost of producing chill castings to a minimum.

CHAIRMAN RISHEL: We have not heard much yet on the length of chill that can be used or the length of section that can be chilled without danger of getting into cracks. I know of one foundry organization who, when having 18-in. of fillet to be chilled, feel that their chills should be tapered, should not be over 7-in. long and that there should be at least 1-in. of sand between each chill. I suppose we will find variation to that.

C. W. BRIGGS[6]: The normal practice in most foundries is to use not over 4-in. long chills. Suppose a fillet of 4- or 5-ft. length requires chilling, the practice would be to use 4-in. long chills interspaced with small brackets.

S. W. BRINSON[7]: We practically follow the same practice Mr. Briggs just mentioned. We use a chill 4-in. or 5-in. long. We put sand between and cut a bracket between that. We have found also that too long a chill will bow down into the casting, especially in the cope side. For most of the chills we have used a rolled section and weld nails. We pound the nails on the back and bend them to hold the sand a little better.

I noticed in Fig. 5 where the flange was chilled, the author had the chill running into the thin section of the fitting. We have found in cases like that we would just drive a crack right up in that spot. In other words, there is a sharp line of demarcation between the chill and hot section and consequently a stress at that point.

I remember a casting we made a number of years ago when we had a chill running across two flanges longitudinally, and we had to stagger the ends of the chills because otherwise it just drove the crack to the end of the chills. So by making a long chill and a short chill and breaking the straight line we managed to get by with it all right.

On our external chilling, and we do not do much, we have found 4- or 5-in. is the best length, with an inch of sand in between and a bracket cut in the sand between the chills gives good results.

R. C. WOODWARD[8]: Mr. Gezelius dwelt somewhat upon the variation in temperature of the metal, which of course is important. I am inclined to agree with the author of the paper, however, that in ordinarily good foundry practice there is not going to be such a wide variation

[6] Technical Engineer, Steel Founders' Society of America, Cleveland, O.
[7] Master Molder, Norfolk Navy Yard, Portsmouth, Va.
[8] Chief Metallurgist, Bucyrus-Erie, South Milwaukee, Wis.

from heat to heat in the temperature of the metal poured. There is an upper limit of course on the refractory life. There is an upper limit to the amount of super-heat that can be obtained in ordinary medium carbon cast steel. Also, there is a lower limit set by the fluidity of the metal. After the metal is tapped from a furnace and into the ladle and a certain amount of cooling takes place, and there is further cooling when emptying into the mold, limitations working both ways in ordinary foundry practice is not going to leave a great deal of room for a variation of temperature. I do not believe that the average foundry, under reasonably good supervision, will have 100° variation in temperature.

Another point, going back quite a way into the feasibility of cast iron and malleable chills, with regard to cast iron, we must remember, of course, there is a large percentage of graphite in cast iron, which acts not as a chill, but rather as an insulator, and in that way cuts down the effectiveness quite markedly of cast iron as a chill. It appears to me cast iron is not nearly so effective a chill as is steel.

J. H. HALL[9]: I think Mr. Woodward rather confused the question of the temperature of the steel that is going to come into contact with the chill, with how long that steel remains in contact with the steel which governs the amount of heat the chill has to absorb. For instance, take the case of a casting 8-ft. long with a fillet in it and chills all along in the fillet. The chills down at the far end where the metal merely arrives and stops have far less heat to absorb and therefore get far less hot and do not stick to the casting as much as the chills at the gate end, because there the steel runs over them so much longer. Exactly the same thing is true of the sand near the gate and the sand away from the gate. The sand at the gate has to resist the temperature of the flowing steel so long and absorbs such a quantity of heat that it is up against it. The steel is cooler when it reaches the sand and chills far from the gate and hence heats them far less.

There is another point I have not heard touched on here and that is the man in the cleaning room who has to deal with the chill which was too small. I know of two foundries belonging to one company in different parts of the country, one of which follows the practice outlined here, with good, heavy chills made of heavy rolled material. There the cleaning room man has a chance to do a good job. In the other foundry they use these quarter-round chills, about ½-in. thick, with a few nails on them and they burn on to quite an extent. As a result the cleaning room man has to get busy and burn them off with a torch. I often question, if you have to do as much torch burning as you see done in the cleaning rooms of some foundries, whether the chill did you any good at all.

R. C. WOODWARD: I would like to add something with regard to the amount of metal which passes over the chill. From the illustra-

[9] Consulting Engineer, Philadelphia, Pa.

tions the author has given us he is chilling production castings, not of a very large size. They do not go to several tons, for instance. They are probably a matter of 100 or a few hundred lb., and on a given casting there is always the same amount of metal and not a great deal of metal passing over that chill. Therefore, from one casting to another, made from the same pattern, he has a fairly uniform condition with regard to the amount of metal that passes over the chill.

MR. MCKEE: A lot of the effectiveness of the chills depends on whether they are sound. We have to take particular care to see that our chills are just about as solid as the castings themselves. Rolled stock, machined stock, would be better for that. It would have a greater heat absorption per volume of metal because it is a closer grained metal.

Sand Control in the British Foundry Industry†

By J. J. Sheehan,* Birmingham, England

1. This report is of a general nature, and as a consequence, of general interest to members of your Association. Particular aspects of the subject are already familiar to you through the *Proceedings* of the Institute of British Foundrymen, the *Bulletins* of the British Cast Iron Research Association and other publications of the British Technical Press, and are very fully indexed in your Association's "Testing and Grading Foundry Sands and Clays."

2. The increase in interest in sand control throughout the foundry industry of Great Britain, has been most marked in recent years. For years, this interest was definitely academic, and extended only slowly from the atmosphere of Government reports and university dissertations to the molding floors of the country.

3. There are many contrasts between the sand practices of the United States and Britain, and not the least is the origin of the technical control now established in both countries. In the United States in 1921, a meeting held by the A.F.A. Board of Directors authorized the use of funds for a "research on natural and synthetic molding sands." In Britain in 1918, Prof. Boswell published, at the instruction of the Ministry of Munitions of War, "A Memoir on British Resources of Refractory Sands for Furnace and Foundry Purposes." In both countries previous to these dates, some individual workers published the results of their investigations. For example, Dr. R. Moldenke in America and John Shaw in England, but it was definitely the board meeting of the A.F.A., and the instructions of a Government department, that started organized research on foundry sands in the respective countries.

4. Without detracting in any way from the scientific and technical value of the work of the universities and Government institutions, the author is strongly of the opinion that the American

* Austin Motor Co., Ltd.

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foundry industry has had an undoubted advantage in having initiated, financed and provided the personnel for this organized research.

HISTORY OF BRITISH SAND CONTROL

5. In addition to John Shaw, others conducted scientific investigations on sand, notably A. B. Searle and A. L. Curtis. In 1918 Prof. Boswell's "Memoir on Refractory Sands" was published, and was followed by Prof. W. G. Fearnside's papers, and the work of G. W. Holmes, O. Smalley and J. E. Fletcher.

6. An important development was the formation, in 1920, of the British Cast Iron Research Association. The appointment, in 1924, of Dr. J. G. Skerl to work under the general supervision of W. J. Rees, Sheffield University, and carry on organized research on the subject of foundry refractories and molding sands was also an aid.

7. In 1930, the Institute of British Foundrymen formed a Subcommittee on Sands. Apart from its specified work in formulating standardized routine tests for sands, this subcommittee has been of inestimable value in interpreting the work of the British Cast Iron Research Association. It has also co-related the work of your Association with British foundry conditions.

8. Most of the members of this subcommittee have presented, to the general meeting and the branch meetings of the Institute, papers as valuable to the personnel of the industry, for the local discussions they created, as for the technical matter they contained.

9. A further considerable important addition to the study of sands, has been the recent formation of the Molding Materials Subcommittee, Iron and Steel Institute. The title of this subcommittee, "Molding Materials Subcommittee," not sands subcommittee, not steel sands subcommittee, is indicative of the nature of the work to be undertaken. This work must cover not only the investigation of steel molding sands, but that mysterious material compo, and the numerous paints and washes with which the steel industry of Britain is blessed or cursed.

10. At the outset this Subcommittee, as well as the Sands Subcommittee of the I.B.F., has been delayed by unending discussions as to the relative merits of the test methods recommended by

the A.F.A., and B.C.I.R.A. and individual modifications of both these recommended methods. In an effort to avoid the consequent delays, a Joint Committee on Sands has now been formed with the sole object of co-relating test methods. The Joint Committee consists of representatives from the B.C.I.R.A., the Iron and Steel Institute, the British Non-Ferrous Metals Research Association and the I.B.F. This step should allow the subcommittee mentioned to devote attention to more immediate and profitable problems of the industry, such as the items mentioned in the program of the Iron and Steel Institute as follows:

(a) The relation of "bond" in naturally bonded and synthetically-bonded sands to "stripping," "burning on," etc., including the properties of reclaimed sand.

(b) The effects of pressure on the sintering and softening of molding sands and "compos."

(c) The volume changes in molding sands and "compos" from 0° to 1400°C., including the effects of composition, grading, ramming density, etc.

TECHNICAL COMMITTEES AND THEIR OBJECTIVES

11. Organized work on sands is now carried out in Britain by the following institutions, and their principal interest indicated as follows: the Molding Materials Subcommittee, Iron and Steel Institute—Steel (Molding Materials); the Sands and Refractories Committee, British Cast Iron Research Association—Cast Iron (Molding Materials); the British Non-Ferrous Metals Research Association—Non-Ferrous Metals (Molding Materials); the Sands Subcommittee, Institute of British Foundrymen—General; Iron, Steel and Non-Ferrous (Molding Materials); Joint Committee—Testing Methods and Standards.

12. Compare organized sand testing and control in your own country. You start with a Joint Committee on Molding Sand Research and develop into specialized subcommittees strictly under the direction of the A.F.A. We start as a series of subcommittees under various controls and are likely to continue so.

13. One very definite handicap of our individuality we have taken steps to eliminate by the formation of the Joint Committee,

and now expect to progress steadily, with the additional hope that there is a special advantage in specialization.

14. The foregoing is a review of the academic aspect of sand testing and control. The actual application of sand control to the industry is receiving also increased attention. This is being done by the Institute of British Foundrymen through its Technical Committee and Branch meetings, influencing the present generation of foundrymen. The British Cast Iron Research Association is also cooperating, by acting as consultants to its member firms, and through its educational program, influencing the coming generation of foundrymen.

15. The composition and constitution of our Institute lends itself admirably to this increasing application of sand control. The Institute is composed of 12 branches and five sections. These branches are formed on a convenient geographical distribution and cover the country. The branches elect annually two members to the Technical Council. The Technical Council receives regularly the reports of the sands and other subcommittees, and are in personal contact with those who are initiating and interpreting the very latest technical developments. These developments are reported back to the Branch meetings either conversationally, by personal contact, or officially, through reports and branch papers. In this way, a widespread interest is developing.

16. The industry will undoubtedly benefit more from this distributed technical ability among its operatives, than it would from a narrow circle of scientific knowledge, however excellent that knowledge may be.

17. The application of this new knowledge is resulting in better practice in the foundries of Great Britain. Synthetic molding sands are being more extensively used. It is being realized also that by studying the quartz grain and the composition of the clay bond of the natural molding sands, every characteristic of the best molding sands can be reproduced, and even undesirable characteristics avoided, so that a synthetic molding sand, instead of being a substitute for, is now considered an improvement upon the natural deposits.

ADVANCES MADE

18. The quality of the natural molding sands is being main-

tained by new additions of prepared clay. In green sand practice, the ratio of dry to green strength is being balanced by like additions. In dry sand practice, horse manure, sawdust, chopped straw, and cowhair are all being dispensed with and adequate temporary dry strength is being obtained by suitable additions of cereal binders. Expansion effects are being minimized by controlled additions of graded coal dust or silica fines.

New Practices

19. Green sand practice is extending in the steel foundries, and, for medium weight castings, dry sand and practice is gaining ground from "compo" mixtures. The "compos," which were mysterious mixtures of old fire bricks, old graphite crucibles, coarse silicon sand, old fire clay pots, all crushed to less than ⅛-in. size, bonded with ganister and fire clay, are now becoming obsolete. A combination of a refractory plastic material and a non-plastic material termed "grog," usually any suitably-fired refractory product, is being substituted. Quoting from the Third Report, Steel Castings Research Committee, Iron and Steel Institute, "A series of tests on 'compo' mixtures of all grades has shown that the assumed virtues of old crucibles from crucible steel melting are illusory. Without exception, the tests show that 'compos' in which the crushed crucible pots are replaced by good clean burned fire clay (*i.e.* grog or chamotte), are at least as good in all properties as the old mixtures."

New Resources Found

20. Parallel with this improvement in practice, there has developed an improved knowledge of the resources of molding materials within the country. It is a tribute to the work initiated by Boswell at the end of the last great war, that the objective sought then, has been obtained in full before this present war. We are now in the fortunate position of being completely independent of overseas sources of molding materials, and to some extent of even internal transport, through a better understanding of local deposits and a fuller use of reclaimed materials.

21. An example will illustrate. A steel foundry in the midlands of England, which previously operated on overseas steel molding sand of good quality, now operates on a controlled synthetic sand with the following advantages:

On the Old Method

(a) Transportation from overseas and from home ports to central England was expensive.

(b) Storage under cover had to be provided to prevent bond being unevenly distributed by heavy winter rains. This storage had to be extensive to accommodate ship load lots.

(c) Processing. Every batch of molding sand was milled for 12 min. to distribute bond and to break up hard dry clay pellets which formed in transport and storage.

(d) Cores were made from the used molding sand and absorbed an excessive amount of core binder. Such cores were unsatisfactory for very obvious reasons.

On the New Method

The whole process is reversed.

(a) Cores were made with silica sands from local deposits selected, among other reasons, to give high strength with a minimum of core binders.

(b) Processing. No new sand, as such, is added to the used molding sand in the mill (sand losses are made good by the disintegration of the burnt used cores), powdered clay and a cereal binder renews the bond. The mixing time has been reduced to 5 min.

(c) Storage. The silica sands are stored in the open, and adequate storage only for car load lots, not ship load lots, is required. (The sand quarries in Britain are worked all the year, winter and summer.)

(d) Transportation is at a minimum from local quarries. (Many foundries in midland districts obtain their sands as a return load for road transport motor trucks.)

SAND CONTROL OF NATIONAL IMPORTANCE

22. Sand control has thus proved to be of national importance in releasing ship space and minimizing internal transport, and of

commercial importance in providing a less expensive raw materal and producing better castings.

23. That latter paragraph must sound to you as a sermon to the converted. We are aware of the more extended use of synthetic sand in your industry. Very frequently in our technical literature that fact is explained by the remark—"The American foundry industry was handicapped by a shortage of suitable natural bonded sands, and as a consequence had to develop a substitute." That explanation is not correct. It is not the reason for your rapid development of synthetic sand technique or our tardy recognition of its advantages. The mechanization of your foundries provides the reason and the explanation.

24. Good natural molding sands, more particularly for high temperature work, are neither abundant nor widely distributed anywhere. The peculiarity of their grading is not an easy task for nature, and to quote Boswell: "The current, which is able to transport fine mud as a cloud of suspended matter, may be unable to move sand, and the stream which rushes down from the hill-country, laden with sand and milky with suspended clay, is not likely to drop all its burden at once. Rather does it first drop the sand as its velocity is checked on its entering quieter water and carries on the mud to a more distant resting place."

Advantages of Synthetic Sands

25. By bringing together in the most desirable proportions what nature has distributed, as in synthetic sand practice, the ideal sand is more nearly achieved; and such a sand is a necessity in mechanized foundry practice.

26. A good molder can make a good mold from very indifferent materials. The machine is particular, it cannot readily react to wide variations in the condition of the materials it has to process. The mechanization in American foundries is receiving the sand practice necessary to it and the increasing mechanization in our foundries is demanding it.

27. The numerous surveys of our natural resources indicate that it is possible to obtain and apply widely this developing technique to our foundry industry. Silica sands of high quality are abundant and in a variety of gradings.

28. In the flooded southern river valleys of both England and

Ireland, extensive deposits of transported clays exist, similar to the clays of Florida, Tennessee, Kentucky and Alabama. Many are similar in geological age (tertiary), and in relative location, *i.e.* at the southern limit of a glacial period. These clays are plastic and refractory. The "white burning" varieties are extensively used in the pottery industries, other varieties are gradually finding employment in our foundries.

SUMMARY

29. Summarizing the condition of sand control in the British foundry industry, it is possible to state with certainty that we have adequate academic facilities, ample raw materials of high quality and the technical ability to use both the knowledge and the materials, but we do need a wider distribution of this technical ability. It is now our most pressing problem, and dependent entirely on our own efforts.

30. Of lesser urgency, but yet of great importance, is the necessity of continually adding to the knowledge we possess. In this necessity it is possible to receive much encouragement from the problems faced and overcome by others. In that respect, we readily acknowledge the assistance already received from the work of the American Foundrymen's Association, and, with confidence, hope for more.

DISCUSSION

Paper presented by Rufus Harrington, Foundry Superintendent and Chief Metallurgist, Hunt-Spiller Mfg. Co., Boston, Mass.

Presiding: D. L. PARKER, General Electric Co., West Lynn, Mass.

MR. HARRINGTON: This paper by an operating man of the Austin Motor Car Co. of England seems particularly interesting to me. It is especially interesting to those of us who had the privilege of attending the International Foundry Congress in England in 1929.

One of the great virtues of American industry is that it has less bias, I believe, less prejudice, than some of the other countries which are now striving for advancement in technical control. We pay our respects to those many foundrymen in this country who are of English, Scotch and Irish descent who have been instrumental in building up our foundry industry. This very splendid paper of Mr. Sheehan's is a distinct compliment to our own American industry and particularly, as the

author has said, to the American Foundrymen's Association and their sand committee work.

It is pleasing to us who were there in 1929 and received a most cordial reception all over Great Britain to realize that the close work between the Institute of British Foundrymen and the American Foundrymen's Association has been helpful in advancing the industry so far as its sand control and research are concerned. It is worth while, indeed, and I think our own organization can feel justly proud that we have been helpful, because, after all, it is the desire of the Association and it is that which makes these meetings worth while as a cooperative effort.

DR. H. RIES[1]: It is most gratifying to have Mr. Sheehan acknowledge the assistance and cooperation that our British friends have received from the American foundry industry.

Mr. Sheehan's statement that: "At the outset, this subcommittee, as well as the sands subcommittee of the I.B.F. has been delayed by unending discussions as to relative merits of the tests methods recommended by the American Foundrymen's Association," starts a train of thoughts in my mind. While it is true that the British foundrymen recognized the importance of the same sand properties that we did, their methods of testing them were originally quite different from ours. It is a source of gratification that they have turned more and more to our methods of technique, even though the types of apparatus used by them may not in all cases be exactly the same as those recommended by the A.F.A. Their Richardson permeability apparatus checks closely in its results with ours. Mr. Frank Hudson and some of his colleagues have done much to correlate the methods used abroad and here.

CHAIRMAN PARKER: One of the aspects of this paper that impressed me was the fact that there is available, to the industry through the American Foundrymen's Association and the Institute of British Foundrymen, a great deal of data that can be and are being applied.

In regard to the reasons that Mr. Sheehan gives for our use of synthetic or blended sands, he refers to the mechanization of American foundries. Now, whether he is referring to our high production molding units, I am not sure, but I do know that there are a number of foundries in the East that are using synthetic sands and they are not mechanized foundries. In our own case, before going to synthetic sands, we ran a large number of machine molding tests, with sand that was shoveled and cut over. It was not put through a muller or anything of that nature. Concentrated additions were made up in a muller and cut in with a sand cutter.

[1] Technical Director, Foundry Sand Research Committee, A.F.A.

The Solidification and Graphitization of Gray Iron*

By C. D. D'Amico† and R. Schneidewind, Ann Arbor, Mich.

Abstract

The authors believe that the probable graphite pattern in any given iron is determined by the rate of cooling of an iron during solidification; the degree of undercooling which the iron experiences by virtue of its cooling rate during solidification; and the solidification characteristics of an iron. This investigation was conducted in an effort to ascertain the validity of this theory. Graphite formation in five irons of widely different compositions was studied by means of undercooling tests. The effect of deoxidation on graphite formation also was investigated. Interpretation of the results is based on photomicrographs of the undercooled samples and data calculated from cooling-curve measurements taken as the individual samples cooled from the molten to the solid state.

1. In practically all research conducted for the purpose of securing a better understanding of the behavior and properties of cast iron, one recognized fact is that the properties of a casting are controlled by the matrix and the graphite pattern. The reactions controlling the properties of the matrix have been widely studied[1,2]** and it has been shown that austenite in cast iron transforms upon cooling through the critical range into ferrite and various forms of pearlite. The ferrite or pearlite, or mixture of the two, represents that portion of the iron which contributes to the strength and hardness.

2. In the last analysis, cast iron may be considered a steel in which the continuity of the matrix is interrupted by the presence

Note: This paper was presented at a Gray Iron Session during the American Foundrymen's Association 44th Annual Convention, Chicago, Ill., May 10, 1940.

* This paper is an abstract of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Metallurgical Engineering at the University of Michigan.

** Superior numbers refer to bibliography at the end of paper.

† Metallurgist, Materials Department, Standard Oil Co. of California, San Francisco, Calif., and Associate Professor of Metallurgy, University of Michigan, respectively.

of graphite flakes. Graphite is the constituent which modifies or weakens the matrix material. For a given amount of graphite, it has been found that the size, shape, and distribution are important factors which control the physical properties of the iron. An increase in the amount of graphite and in the flake size, or an unfavorable distribution, each produce an adverse effect on the strength of cast iron. Variations in such properties as transverse deflection, machinability, and wear resistance are frequently associated with the nature of the graphite pattern.

3. Since the graphite pattern has such a pronounced influence on the properties of cast iron, much effort has been expended to determine the exact nature of the process of graphite formation and the manner in which it may be controlled. In a previous paper[3], presented by the authors, it was shown that rate of cooling and its attendant effect are two of the more significant factors which determine the type of graphite pattern obtained in any given iron. These conclusions were drawn from the results of experimental undercooling tests and temperature of solidification measurements made at various points along a wedge of cast iron containing 2.78 per cent carbon and 1.50 per cent silicon.

4. The results showed that, with rapid rates of cooling, appreciable undercooling accompanies solidification; that is, the metal remains molten until a temperature well below the theoretical freezing point is reached. It also was observed that the faster the rate of cooling, the greater the degree of undercooling.

5. In the metallographic examination of the wedge, all the various types of graphite patterns were observed. It was noted that as the section size decreased, or the rate of cooling increased, the graphite pattern gradually changed from a long flake in normal arrangement to a very fine flake in a highly dendritic arrangement, commonly referred to as eutectiform graphite. With very rapid rates of cooling, graphitization was suppressed with the formation of mottled and white irons. The study of the microstructure in many other wedges also showed that variations in basic composition, alloy additions, and ladle treatments merely influence the section size in which each of the various graphite patterns are formed, but their relative positions to one another remains the same. The results of the wedge study, summarized in Table 1, would indicate that the graphite pattern might be specifically related to the amount of undercooling.

Table 1

SUMMARY OF TEMPERATURE DATA OBTAINED FROM WEDGE CASTING

Station No.	*Thickness of Wedge, In.*	*Soldification Temp. °F.*	*Nature of the Iron*
1	0.19	1800	White Iron—no graphite
2	0.50	1975	Mottled Iron—eutectiform graphite
3	0.875	1990	Gray Iron—eutectiform graphite in dendritic distribution
4	1.31	...	About same as (3)
5	1.75	...	Gray Iron—normal flake graphite
6	2.31	2030	Gray Iron—normal flake graphite

6. To obtain more direct evidence as to this correlation, a series of undercooling tests, discussed in the above paper,[3] were also carried out. The tests consisted in casting small samples of molten iron into a metallic mold maintained at such predetermined temperatures that solidification took place below the theoretical freezing point. The nature of the graphite patterns obtained in a series of samples made to solidify at successively lower temperatures is summarized in Table 2. The results are in accord with the observa-

Table 2

INFLUENCE OF TEMPERATURE OF SOLIDIFICATION UPON THE GRAPHITE PATTERN IN A GRAY IRON

Sample No.	*Mold Temp., °F.*	*Type of Graphite*
10-A	2070	Mottled Iron. Carbides plus nests of eutectiform graphite.
12-A	2060	Gray Iron. Normal flake graphite.
9-A	2040	Gray Iron. Normal flake graphite.
7-A	1992	Gray Iron. Same short flake graphite. Some eutectiform graphite in dendritic dispersion.
8-A	1970	Gray Iron. Eutectiform graphite in very dendritic dispersion.
13-A	1955	Mottled Iron. Carbides plus eutectiform graphite.
6-A	1818	White Iron. Traces of graphite and some temper carbon formed during cooling.

tions made in the wedge study and show that the graphite pattern is directly related to the degree of undercooling. The change from a normal, long flake graphite to a highly dendritic, eutectiform graphite appeared to be a gradual transition process controlled principally by the extent of undercooling.

7. From the results of this first investigation, it would seem probable that the graphite pattern in any given iron may be determined by the following three factors:

1. The rate of cooling of an iron during solidification.
2. The degree of undercooling which the iron experiences by virtue of its cooling rate during solidification.
3. The solidification characteristics of an iron. This term may be defined as the behavior of an iron when cooled at any given rate; that is, whether it solidifies in the white, mottled, or gray state; and, if gray iron results, whether the graphite forms as long normal flakes, as fine eutectiform graphite in a dendritic distribution, or as an intermediate type of structure.

According to this reasoning, the influence of factors, which affect the nature of the graphite pattern, would only be attributed to their ability to change the solidification characteristics of an iron exposed to any given amount of undercooling.

8. The investigation related in the present paper was conducted in an effort to ascertain the validity of the above hypothesis. Graphite formation in five irons of widely different compositions listed in Table 3 was studied by means of undercooling tests similar to those described in the first paper. The effect of deoxidation on graphite formation was investigated in the same manner. Interpretation of the results is based on photomicrographs of the undercooled samples and data calculated from cooling-curve measure-

Table 3

CHEMICAL COMPOSITION OF TEST IRONS

Iron Designation	*Chemical Composition*					*Per cent Eutectic at Eutectic Solidification Temperature*
	Total Carbon, Per cent	*Silicon, Per cent*	*Manganese, Per cent*	*Sulphur, Per cent*	*Phosphorus, Per cent*	
B	3.74	2.10	0.68	0.029	0.094	100
E	3.25	1.99	0.69	0.037	0.099	85
H	3.06	1.64	0.67	0.029	0.089	72
I	3.05	1.97	0.69	0.027	0.095	76
K	3.00	2.99	0.65	0.029	0.090	90

ments taken as the individual samples cooled from the molten to the solid state.

PROCEDURE AND RESULTS

9. The test irons were melted in an indirect electric rocking type furnace, using the same raw materials in each charge and identical melting practices in each heat. The irons were cast into the form of metal shot by pouring the molten metal as a fine stream into a 60 gal. drum of water. It was desired to obtain the metal in this form in order to facilitate handling and promote rapid remelting in the undercooling tests.

Melting and Casting—Undercooling Tests

10. Heats of iron, 150 grams in weight, were melted in a magnesium oxide crucible placed in a horizontal-hearth Globar furnace. The superheating temperature was 2650°F. and the temperature of pouring 2500°F. A 15-20 gram portion of the molten metal was cast into the split mold of heat resisting alloy, shown in Fig. 1. The mold was placed in a vertical, shunt-wound electric furnace, in such a manner that the temperature difference between the top and bottom of the mold could be maintained manually within a range of about 4°F. The temperature of the mold was regulated with the aid of a chromel-alumel thermocouple which extended through the thermocouple well into the casting chamber for a distance of about $\frac{1}{16}$-in. The thermocouple was coated with a refractory mixture containing 90 per cent silica flour and 10 per cent bentonite to eliminate the danger of contamination of the couple and possible alloying of the melt.

Cooling-Curve Measurements

11. As soon as a heat was poured, time-temperature measurements were taken at 5-sec. intervals for a period of 4 min. on a semi-precision potentiometer. The mold was then removed from the furnace, the sample extracted and allowed to cool in air. A series of such tests were made with each of the irons, using mold temperatures varying from just below the theoretical freezing point to a temperature which resulted in the formation of white iron.

12. Time-temperature cooling curves were drawn for each heat with the aid of the recorded cooling-curve data. Since the thermocouple was imbedded in the cast sample, the recorded measurements represent variations in the actual temperature of the metal

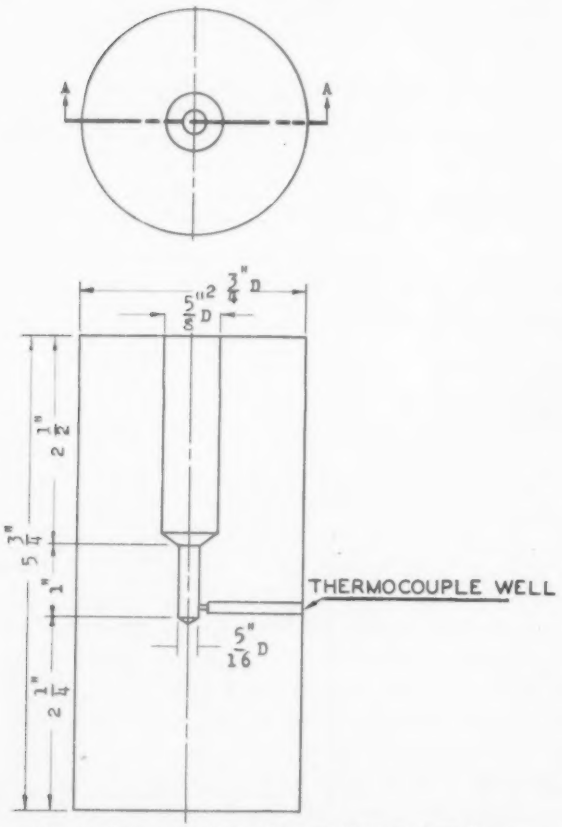

FIG. 1—SKETCH OF MOLD USED IN UNDERCOOLING TESTS.

as it cooled from the molten state. Several typical cooling curves of hypoeutectic iron *I*, illustrating the effect of decreasing mold temperature on the temperature of solidification, are presented in Figs. 2 and 3. Examination of these curves show that solidification does not begin until a finite time has elapsed and continues for a measureable length period of time over a range of temperatures averaging about 15° to 20°F. above that of the mold.

13. As would be expected, the cooling curves of the hypoeutectic irons showed an austenite hump during the freezing of the primary austenite and an arrest during solidification of the eutectic. Eutectic iron *B* exhibited only a single arrest, designating the freezing of the eutectic liquid. Both the austenite hump and the eutectic arrest became less distinct as the extent of undercooling

increased, thereby making it difficult to determine the exact time and temperature at which solidification started and finished. It was found that by plotting the cooling curve data as increments of millivoltage drop in temperature corresponding to time intervals of 5 seconds, the start and the end of solidification of the austenite and of the eutectic could be readily estimated within a range of about plus or minus 5 seconds.

14. The cooling-curve data of Figs. 2 and 3 are presented in this manner in Figs. 4 and 5. The temperatures corresponding to the time values obtained from such plots then were obtained from the time-temperature cooling curves. The average temperatures of solidification of each heat were computed by graphical integration of the cooling curves. The results indicated that, in each iron, the time required to initiate solidification and the time to complete the

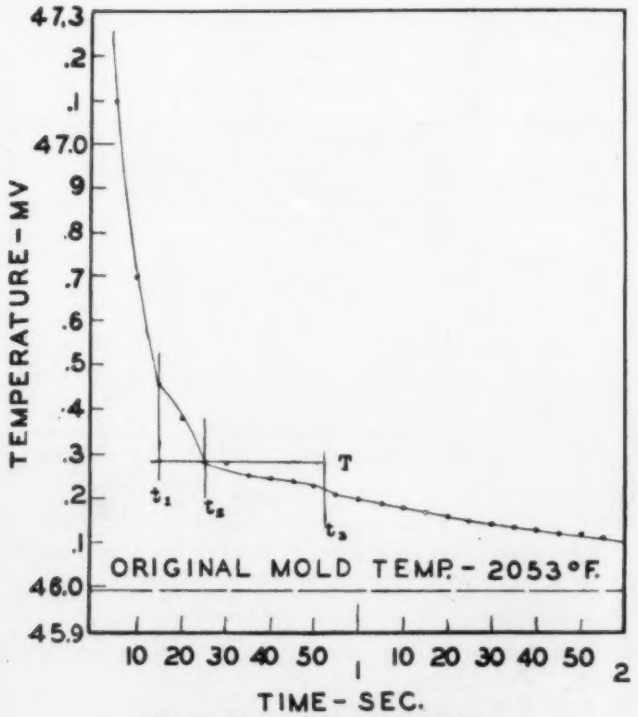

FIG. 2—COOLING CURVE FOR SAMPLE I-1.

t_1 = TIME AT START OF PRIMARY AUSTENITE SOLIDIFICATION—15 SEC. AVERAGE.
t_2 = TIME AT START OF EUTECTIC SOLIDIFICATION—25 SEC. AVERAGE.
t_3 = TIME AT END OF EUTECTIC SOLIDIFICATION—50-55 SEC.
T = AVERAGE TEMPERATURE OF SOLIDIFICATION—2067°F.

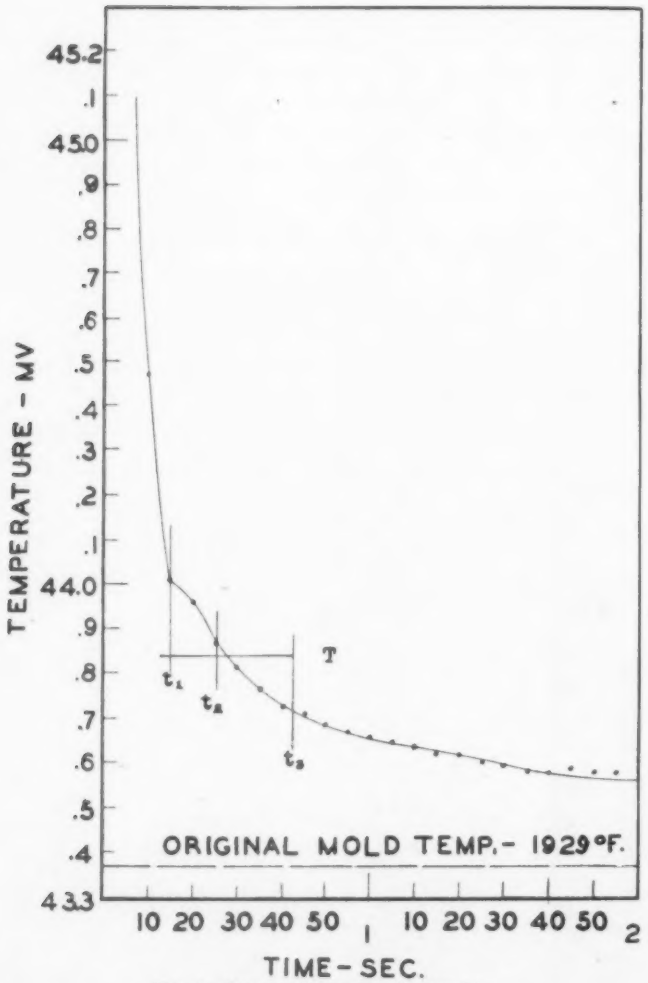

FIG. 3—COOLING CURVE FOR SAMPLE I-9.

t_1 = TIME AT START OF PRIMARY AUSTENITE SOLIDIFICATION—15 SEC. AVERAGE.
t_2 = TIME AT START OF EUTECTIC SOLIDIFICATION—25 SEC. AVERAGE.
t_3 = TIME AT END OF EUTECTIC SOLIDIFICATION—40-45 SEC.
T = AVERAGE TEMPERATURE OF SOLIDIFICATION—1951°F.

process depended to a large extent on the temperature of solidification.

Correlation of Time for Solidification with Temperature

15. A study then was made to determine the influence of undercooling on the time required for solidification, by plotting the

logarithm of the time at the start and at the end of solidification versus the corresponding temperatures. Typical results are illustrated and discussed with the aid of the curves obtained with eutectic iron *B* and hypoeutectic iron *I*, shown in Figs. 6 and 7, respectively. In Fig. 6, the start of solidification of the eutectic is represented by line *ABCD* and the end by *EFGH*. In Iron *I*, primary austenite crystallizes before the eutectic freezes. Line *ABCD* in Fig. 7, therefore, designates the start of solidification of primary austenite and line *EFGH*, the end. The beginning of solidification of the eutectic liquid also is indicated by the latter line; the end of the process is represented by line *JKLM*. Similar curves obtained for irons *E*, *H*, and *K* are presented in Figs. 8, 9 and 10.

16. The general shape of the curve obtained for each of the irons is practically the same and consists of three branches connected in such a manner that they resemble the letter "*S*." In the upper branch of the curve, increasing amounts of undercooling hasten both the start and end of solidification. After the minimum time value is reached, further undercooling promotes a gradual

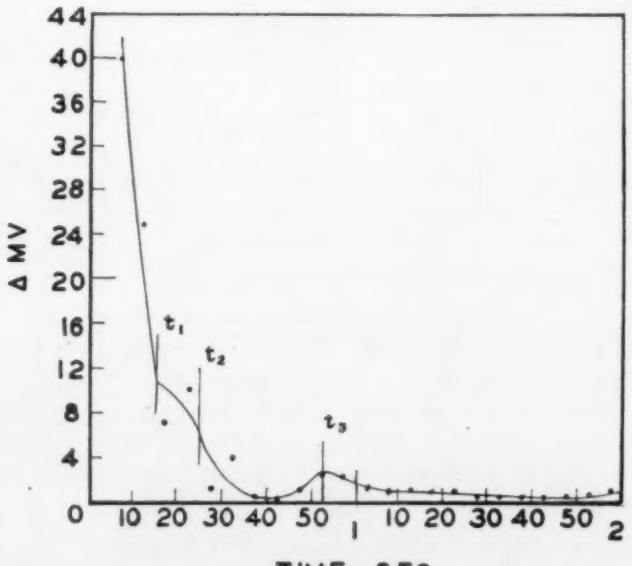

FIG. 4—CHART SHOWING TIME INTERVALS REQUIRED FOR BEGINNING OF PRIMARY AUSTENITE SOLIDIFICATION AND TIME REQUIRED FOR EUTECTIC SOLIDIFICATION FOR SAMPLE I-1.

t_1 = TIME AT START OF PRIMARY AUSTENITE SOLIDIFICATION—15 SEC. AVERAGE.
t_2 = TIME AT START OF EUTECTIC SOLIDIFICATION—25 SEC. AVERAGE.
t_3 = TIME AT END OF EUTECTIC SOLIDIFICATION—50-55 SEC.

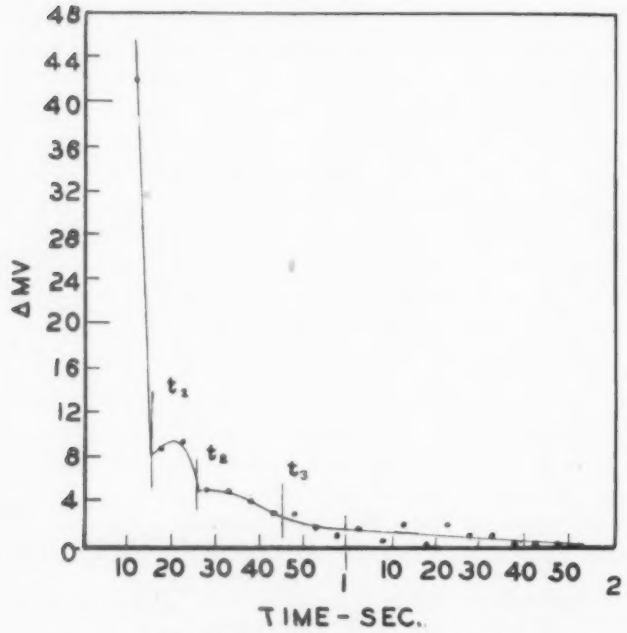

FIG. 5—SAME AS FIG. 4 FOR SAMPLE I-9.

t_1 = TIME AT START OF PRIMARY AUSTENITE SOLIDIFICATION—15 SEC. AVERAGE.
t_2 = TIME AT START OF EUTECTIC SOLIDIFICATION—25 SEC. AVERAGE.
t_3 = TIME AT END OF EUTECTIC SOLIDIFICATION—40-45 SEC.

increase in the time required to initiate and to complete solidification until a maximum time value is attained. In the third branch, increasing degrees of undercooling again cause a gradual decrease in the time to start and end solidification.

17. This type of S-curve is familiar, as it has been encountered in studies pertaining to the process of austenite transformation in steel and cast iron[1,4]. The similarity between the well known Bain S-curve and those obtained in this investigation, points to the possibility that the process of solidification of cast iron might have many characteristics in common with the austenite-to-pearlite transformation.

Correlation of Graphite Patterns with S-Curves

18. The undercooled test samples then were examined microscopically to follow the effect of undercooling on the graphite pattern and, if possible, to establish a relationship between the type of graphite pattern and the characteristics of the S-curve of each

iron. The changes in the graphite pattern affected by increasing amounts of undercooling are illustrated in Figs. 11 to 16, taken from iron samples *B* and *I* at 250 diameters in the unetched condition.

19. The results are consistent with those obtained in the previous investigation and may be briefly summarized as follows: Small amounts of undercooling promote the formation of long flake graphite in normal distribution. As the degree of undercooling is increased, the graphite flakes become smaller in size and assume an increasingly dendritic arrangement. At the same time, the size of the cell pattern outlined by the graphite in dendritic distribution continually diminishes. When the degree of undercooling surpasses a limiting amount, complete precipitation of the graphite is inhibited with the formation of mottled and white iron.

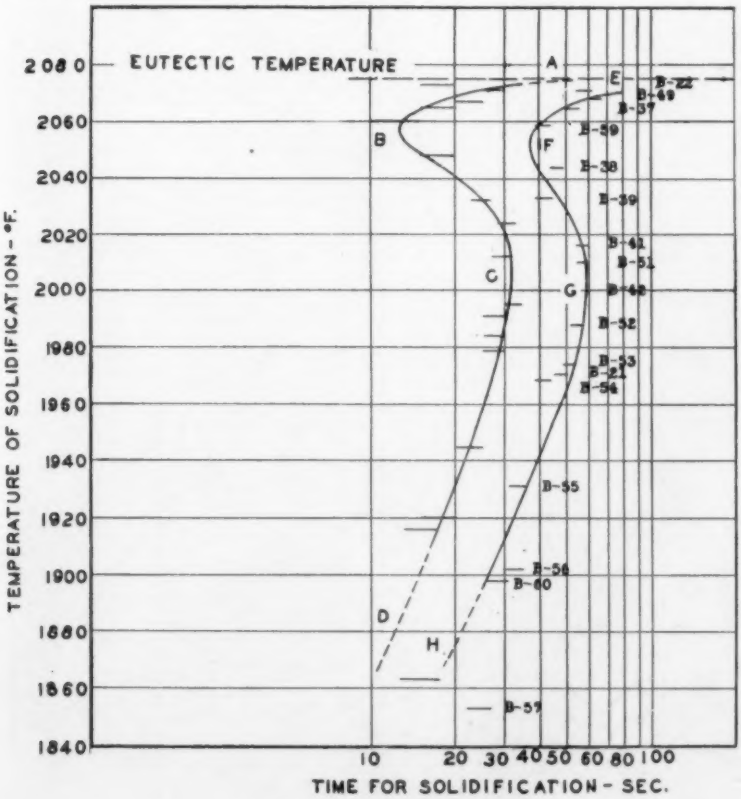

FIG. 6—S-CURVE FOR IRON B.

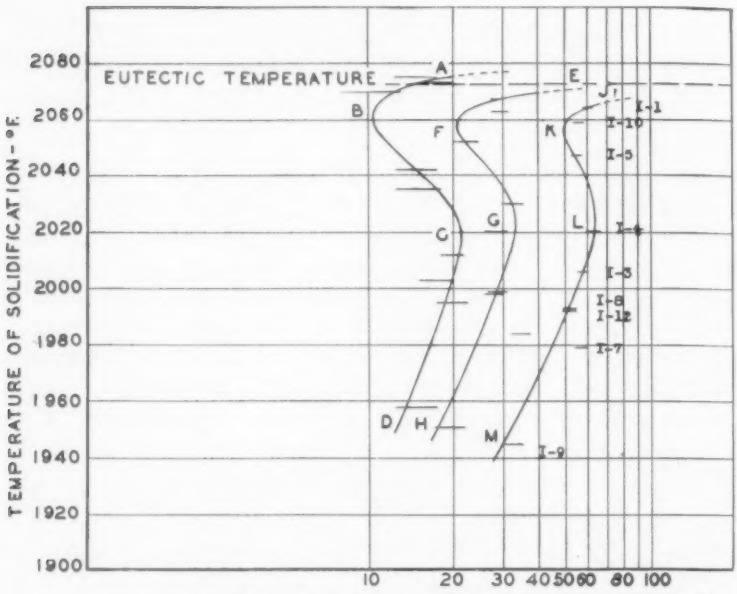

FIG. 7—S-CURVE FOR IRON I.

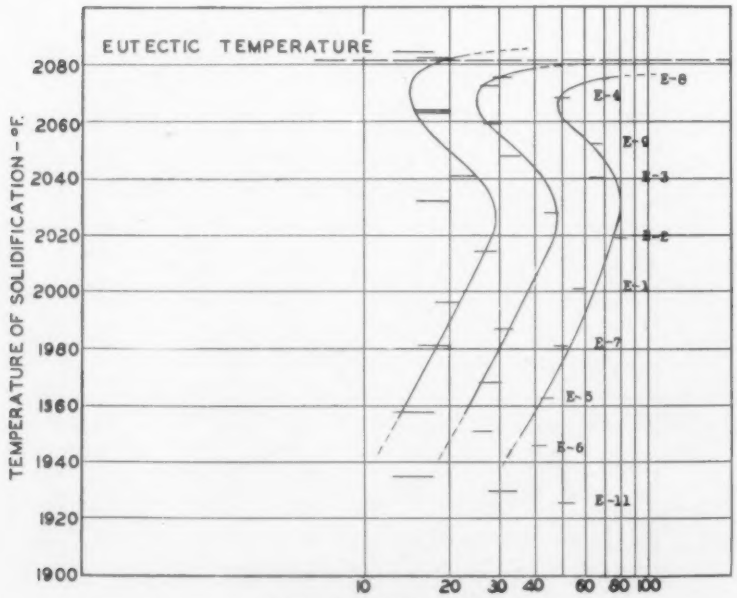

FIG. 8—S-CURVE FOR IRON E.

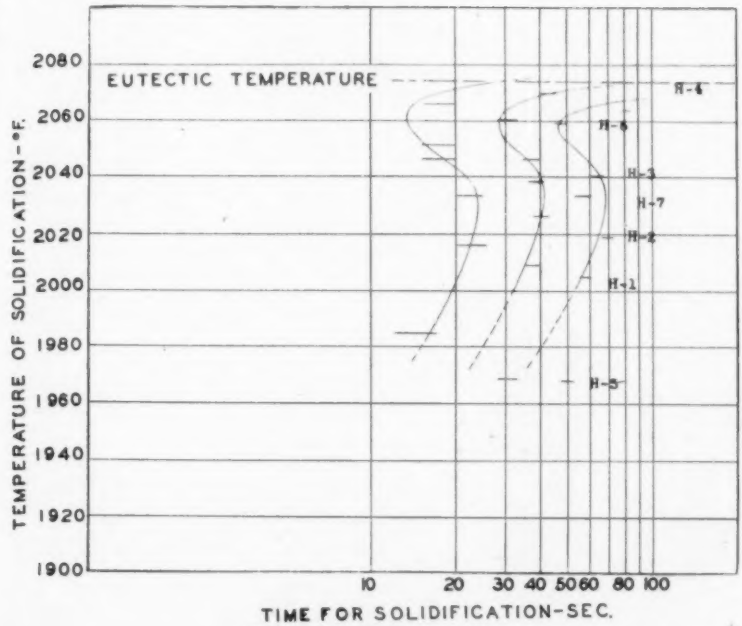

FIG. 9—S-CURVE FOR IRON H.

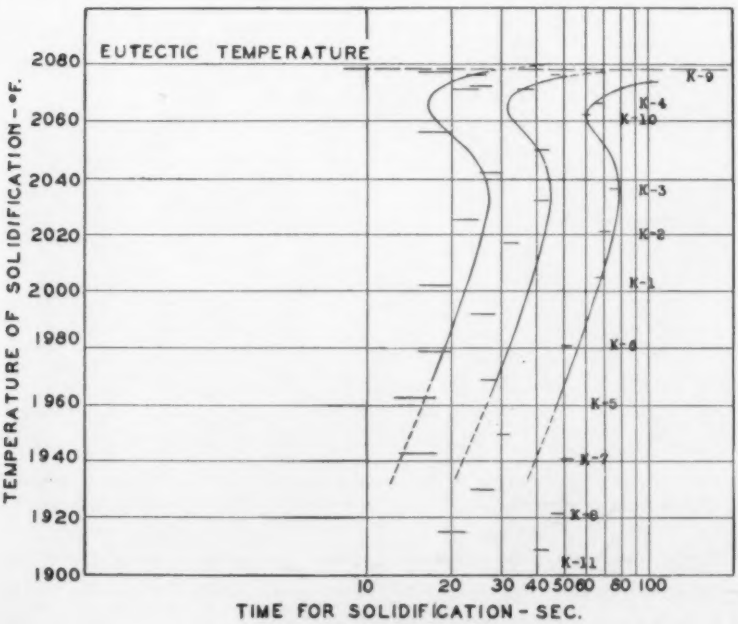

FIG. 10—S-CURVE FOR IRON K.

FIG. 11—TOP—PHOTOMICROGRAPH OF UNDERCOOLED SAMPLE I-1 OF IRON I WHICH SOLIDIFIED AT 2067°F. BOTTOM—SAMPLE I-10 WHICH SOLIDIFIED AT 2061°F. BOTH UNETCHED, X250.

20. The location of these various graphite patterns, with respect to their position on the S-curve, is illustrated with the aid of the photomicrographs and S-curve of Iron *I* (Fig. 7). At the top

of the upper branch of the S-curve, long flake graphite in a random distribution is observed (Fig. 11—Top). As the minimum time value of the curve is approached, the graphite flakes become smaller

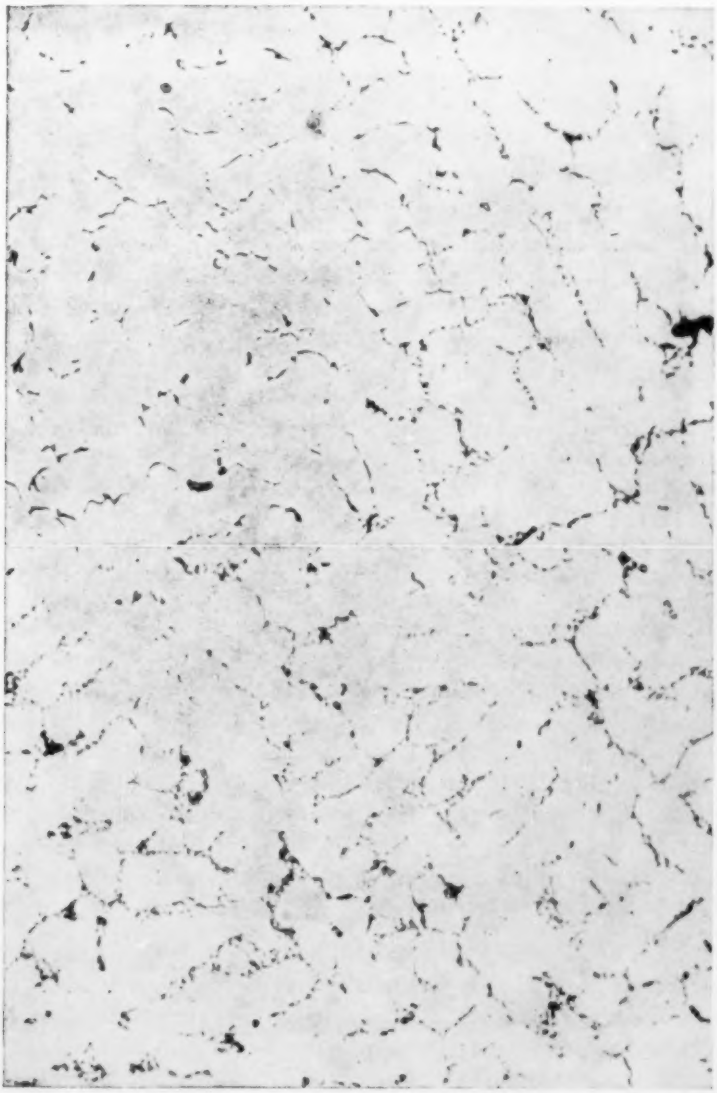

FIG. 12—TOP—PHOTOMICROGRAPH OF UNDERCOOLED SAMPLE I-5 OF IRON I WHICH SOLIDIFIED AT 2052°F. BOTTOM—SAMPLE I-3 WHICH SOLIDIFIED AT 2015°F. BOTH UNETCHED, X250.

in size, more numerous, and tend to be distributed in a dendritic arrangement (Fig. 11—Bottom). The graphite formed in the middle branch is characterized by its distinctly dendritic pattern. Increasing amounts of undercooling in this region result in a gradual change from a short flake eutectiform graphite (Fig. 12—Top) to a very fine eutectiform pattern, referred to as lacy eutectiform graphite (Fig. 12—Bottom). In the lower branch, solidification takes place with the formation of the metastable carbide phase, and first mottled (Fig. 13—Top) then white iron (Fig. 13—Bottom) is produced.

21. A slight variation from this general relationship was noted in the cases of irons *B* and *K*. In the upper branch of the S-curve of these irons, the graphite does not appear as individual flakes; instead, small flakes seem to grow from the sides of larger flakes at numerous points giving rise to the interlacing type of structure visible in Fig. 14—Top. The graphite patterns in the middle and lower branches of these curves are the same as those exhibited by the other irons. The explanation for this peculiar behavior is based on the fact that both irons are practically eutectic in composition, containing high carbon and silicon contents (see Table 3).

22. The extremely great urge for graphitization in irons of such compositions is readily appreciated. When these irons are suddenly cooled to a temperature below the theoretical freezing point, they become highly supersaturated with respect to carbon and tend to reject carbon rapidly. Conditions prevailing in the undercooling tests demand, moreover, that solidification take place in a limited length of time. For these reasons, some graphite starts to grow as long flakes, but before they can assume any appreciable length, smaller flakes grow from the sides of the already existing flakes as well as from new nuclei within the eutectic melt. Such circumstances would inevitably lead to the formation of the "irregular" structures noted.

23. Aside from this variation, it was found that the graphite pattern observed at any particular point in the S-curve of each of the irons is characteristic of that point alone; that is, there is one, and only one, graphite pattern common to an iron undercooled to a given temperature. Furthermore, at corresponding points in the S-curves of different irons, the graphite patterns are essentially the same. Each of the irons exhibit different S-curves and, there-

FIG. 13—TOP—PHOTOMICROGRAPH OF UNDERCOOLED SAMPLE I-12 OF IRON I WHICH SOLIDIFIED AT 1996°F. BOTTOM—SAMPLE I-9 WHICH SOLIDIFIED AT 1951°F. BOTH UNETCHED, X250.

fore, different graphite patterns with similar amounts of undercooling. This behavior is attributed to individual characteristics of solidification of each iron.

The Effect of Deoxidation

24. The influence of deoxidation on the nature of the graphite patterns formed in iron *B* at different degrees of undercooling was

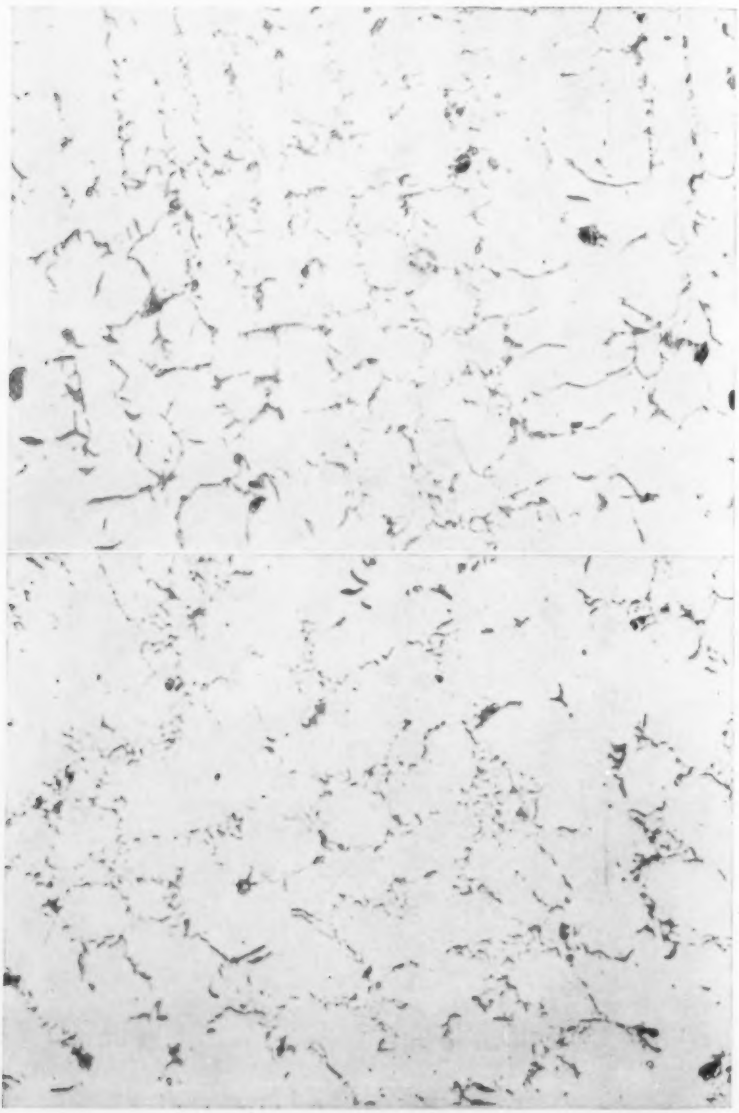

FIG. 14—TOP—PHOTOMICROGRAPH OF UNDERCOOLED SAMPLE B-23 OF IRON B WHICH SOLIDIFIED AT 2072°F. BOTTOM—SAMPLE B-38 WHICH SOLIDIFIED AT 2053°F. BOTH UNETCHED, X250.

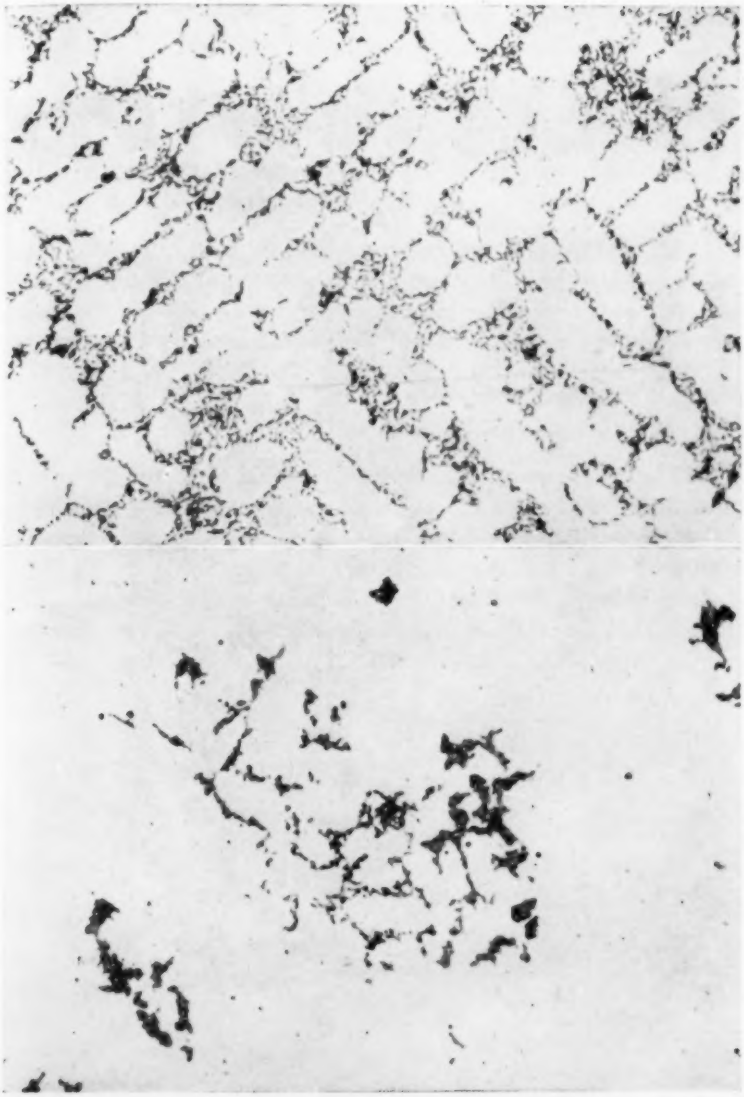

FIG. 15—TOP—PHOTOMICROGRAPH OF UNDERCOOLED SAMPLE B-52 OF IRON B WHICH SOLIDIFIED AT 1990°F. BOTTOM—UNDERCOOLED SAMPLE B-60 WHICH SOLIDIFIED AT 1899°F. BOTH UNETCHED, X250.

determined by repeating this series of tests with the addition of calcium silicide to the molten metal before casting. Calcium silicide of the following analysis was used in these tests: 60-65 per cent

silicon, 2-4 per cent iron, and the remainder calcium. Three series of tests were carried out containing, respectively, 0.16, 0.40, and 0.72 per cent calcium silicide. These proportions of deoxidizers are somewhat greater than those employed in commercial practice, but it was found that these amounts were necessary in order to obtain any appreciable degree of effective deoxidation under the conditions of melting employed in the investigation.

25. The melting and casting procedure used in the deoxidizer tests was identical to that employed in the previous undercooling tests. Time-temperature measurements were recorded as before, and cooling curves were plotted for each heat. The time and temperature of solidification were obtained with the aid of $\frac{\Delta \text{ Mv}}{\Delta \text{ Time}}$ vs. time graphs, as previously described.

26. The S-curve shown in Fig. 17 was drawn with the cooling curve data obtained in the series of tests deoxidized with 0.40 per cent calcium silicide. Comparison of this curve with that obtained with the plain iron (Fig. 6) shows that deoxidation has the effect of "stretching" the latter curve along the temperature axis. It is realized that the addition of 0.40 per cent calcium silicide increases

FIG. 16—PHOTOMICROGRAPH OF UNDERCOOLED SAMPLE B-23 OF IRON B WHICH SOLIDIFIED AT 1660°F. UNETCHED, X250.

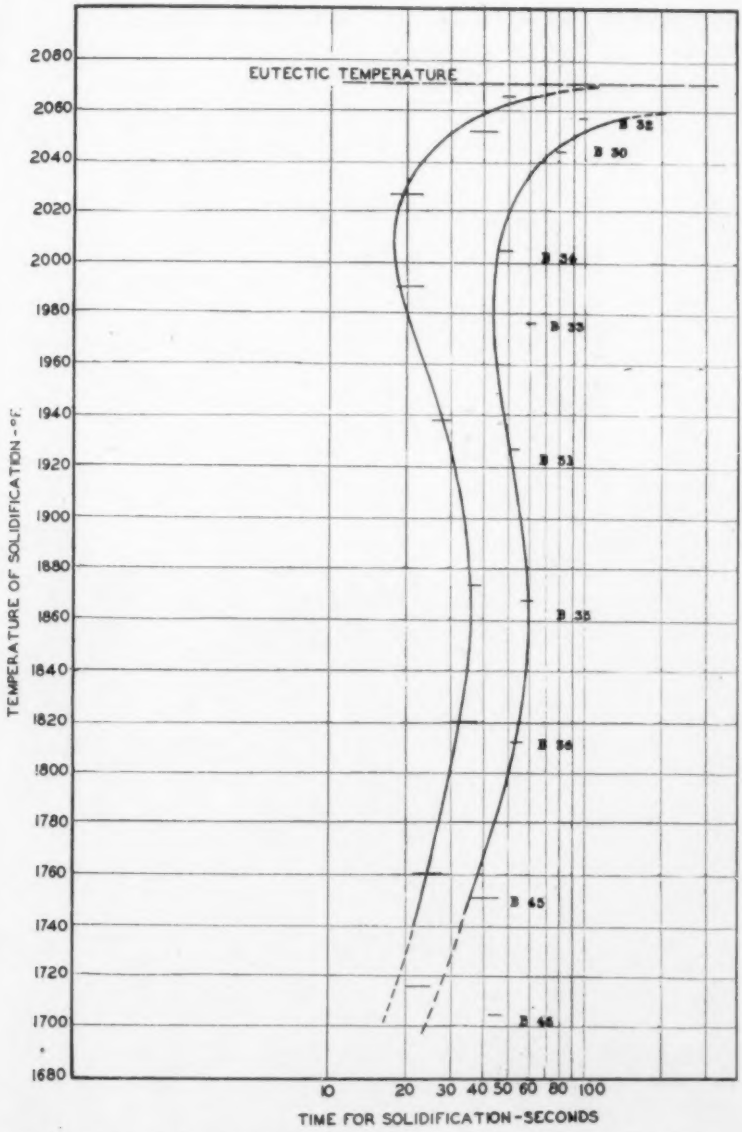

FIG. 17—S-CURVE FOR IRON B DEOXIDIZED WITH 0.40 PER CENT CALCIUM SILICIDE.

the silicon content of the iron by about 0.20 per cent. Comparison of the S-curve of the deoxidized iron with those obtained in the preceding tests show conclusively, however, that this small addition

of silicon can only account for a minor change in the shape of the curve.

FIG. 18—PHOTOMICROGRAPHS OF UNDERCOOLED SAMPLES OF IRON B DEOXIDIZED WITH 0.40 PER CENT CALCIUM SILICIDE. TOP—SAMPLE B-32 WHICH SOLIDIFIED AT 2064°F. BOTTOM—SAMPLE B-30 WHICH SOLIDIFIED AT 2046°F. BOTH UNETCHED, X250.

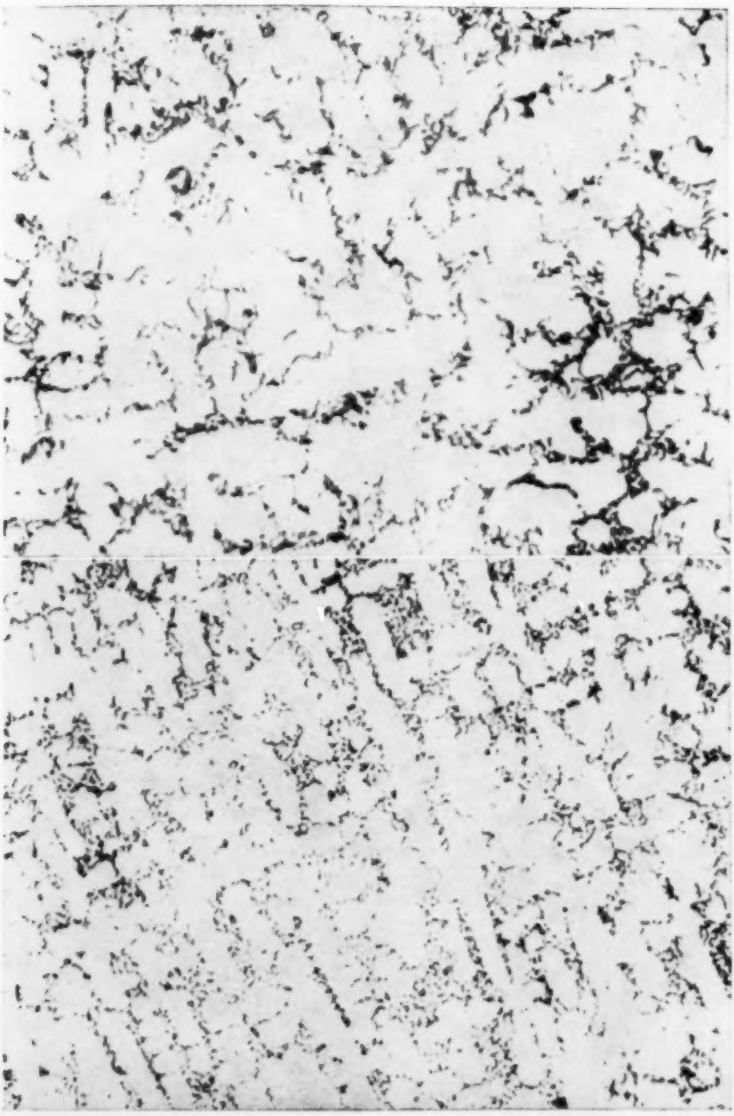

FIG. 19—PHOTOMICROGRAPHS OF UNDERCOOLED SAMPLES OF IRON B DEOXIDIZED WITH 0.40 PER CENT CALCIUM SILICIDE. TOP—SAMPLE B-31 WHICH SOLIDIFIED AT 1933°F. BOTTOM—SAMPLE B-86 WHICH SOLIDIFIED AT 1815°F. BOTH UNETCHED, X250.

27. The characteristics of the S-curve of the deoxidized iron may undoubtedly be attributed to the deoxidizing influence of the

calcium silicide. Although sufficient time was not available to obtain data with which to draw S-curves for the other two series

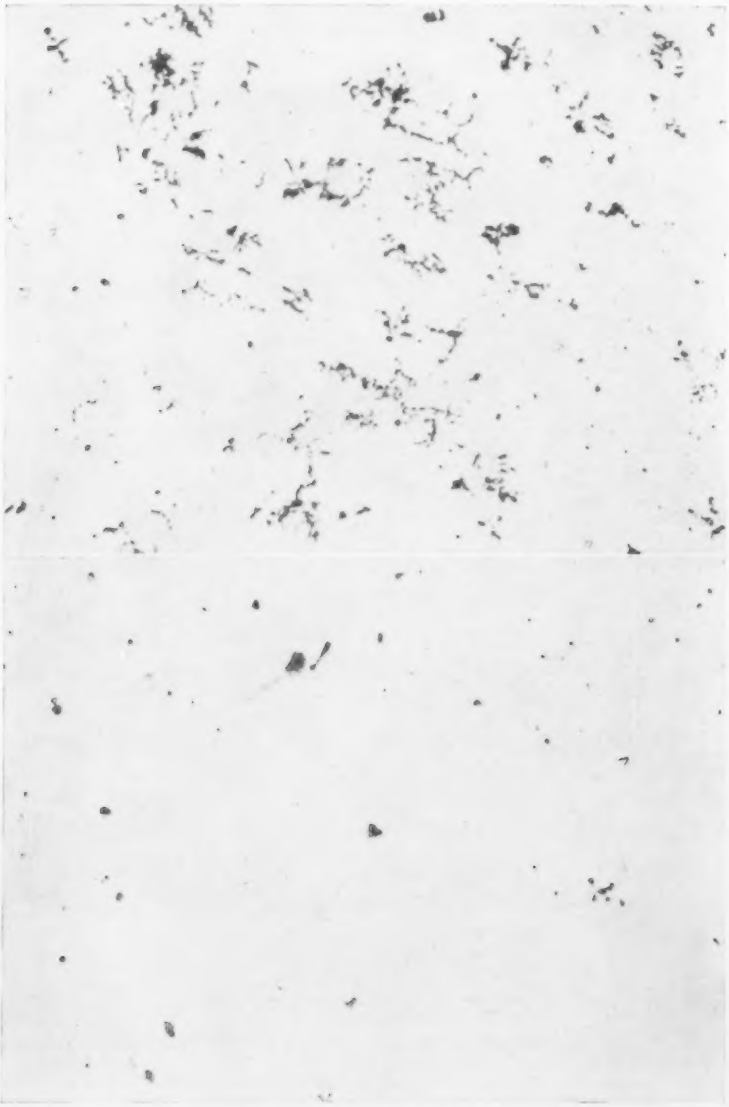

FIG. 20—PHOTOMICROGRAPHS OF UNDERCOOLED SAMPLES OF IRON B DEOXIDIZED WITH 0.40 PER CENT CALCIUM SILICIDE. TOP—SAMPLE B-48 WHICH SOLIDIFIED AT 1516°F. BOTTOM—SAMPLE B-61 WHICH SOLIDIFIED BELOW 1400°F. BOTH UNETCHED, X250.

of deoxidized tests, it seems likely that the degree of deoxidation would have a pronounced influence on the extent to which the S-curve for the plain iron is altered.

28. Examination of photomicrographs in Figs. 18 to 20 inclusive, taken of the series of undercooled samples deoxidized with 0.40 per cent calcium silicide, reveals that the changes in the graphite pattern brought about by increasing amounts of undercooling are the same as those noted in the plain irons. The patterns formed in each of the three branches of the S-curve of the deoxidized iron are, moreover, identical to those observed in the case of the plain irons.

29. It is interesting to note that deoxidation with 0.40 per cent calcium silicide has made it necessary to undercool iron *B* to 1450 and 1750°F., respectively, in order that white and mottled structures are obtained. The corresponding temperatures in the untreated iron are 1675 and 1925°F. In other words, the tendency to form gray iron, or the urge to graphitize, is much stronger in a deoxidized iron than in a plain iron of the same composition; the addition of a deoxidizer demands much more drastic undercooling for the formation of the metastable carbide phase.

30. From a practical standpoint, this means that, for a given analysis, a gray iron fracture can be obtained in smaller section sizes with a deoxidized iron than with a plain iron of the same composition. The more gradual change in the graphite pattern accompanying undercooling of the deoxidized iron also seems to explain why deoxidation renders an iron less sensitive to variations in section size in commercial castings.

31. The influence of the degree of deoxidation on graphite formation at a given temperature of solidification is revealed in the micrographs of the following samples which were treated with different amounts of deoxidizer and made to freeze at about 2050°F. Sample B-38 (Fig. 14—Bottom), melted plain; and Sample B-29 (Fig. 21—Bottom), Sample B-30 (Fig. 18—Bottom) and Sample B-44 (Fig. 21—Top), deoxidized respectively with 0.16, 0.40, and 0.72 per cent calcium silicide. The graphite in the plain iron is of the short flake eutectiform type in a highly dendritic arrangement. As the degree of deoxidation is increased, the graphite tends to form long flakes in a normal arrangement. These results are in full accord with commercial observations which disclose that, in

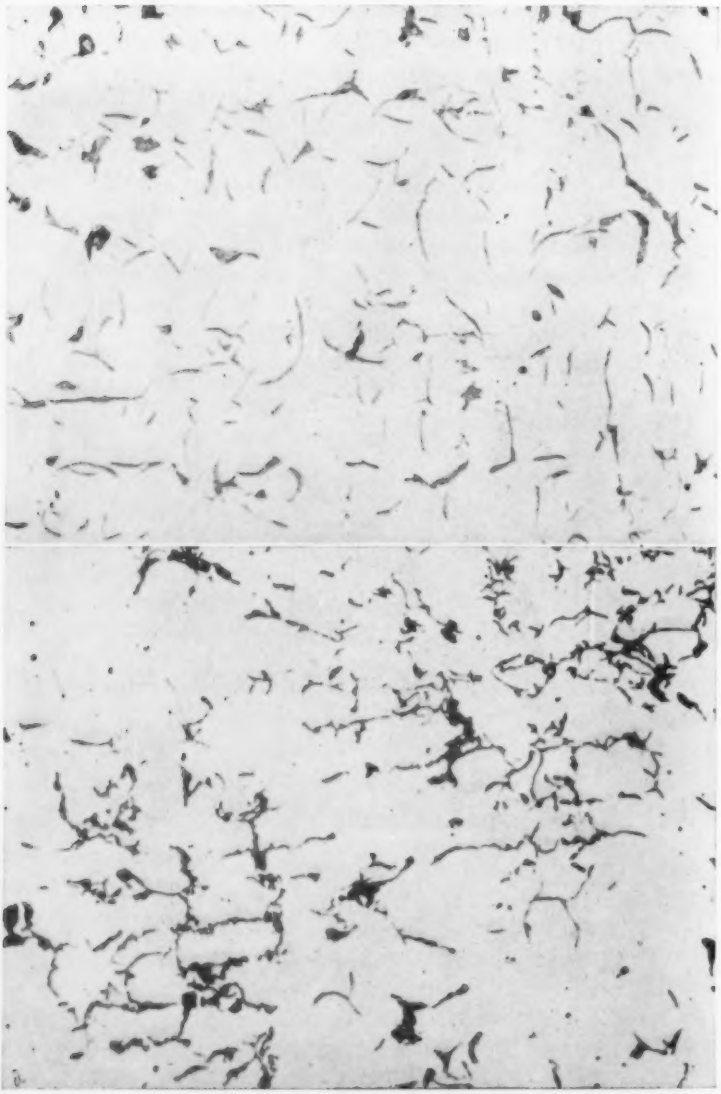

FIG. 21—PHOTOMICROGRAPHS OF UNDERCOOLED SAMPLES OF IRON B. TOP—SAMPLE B-44, DEOXIDIZED WITH 0.72 PER CENT CALCIUM SILICIDE, WHICH SOLIDIFIED AT 2046°F. BOTTOM —SAMPLE B-29, DEOXIDIZED WITH 0.17 PER CENT CALCIUM SILICIDE, WHICH SOLIDIFIED AT 2052°F. BOTH UNETCHED, X250.

general, deoxidation promotes the formation of a more normal, flake graphite pattern in a given iron cast into a given section size.

32. From a theoretical point of view, the effect of deoxidation might be attributed to either, or both, of two phenomena, namely:

1. Deoxidation might influence the solidification characteristics of an iron; and

2. The addition of a deoxidizer to a plain iron might raise its temperature of solidification.

Both phenomena would result in the formation of a more normal graphite pattern. The results of the deoxidized undercooling tests indicate that the former probably takes place but offers no clue as to the possibilities of the latter.

33. To determine whether or not deoxidation influences the actual temperature of solidification, a determination was made of the freezing temperatures of two standard 1.2-in. diameter transverse test bars cast, respectively, of a plain iron and a deoxidized iron of the same composition. The iron selected for this study contained 3.0 per cent carbon and 2.0 per cent silicon. It was melted in an indirect arc, electric, rocking-type furnace. A superheating temperature of 2800°F. was used and the metal was poured at 2600 to 2650°F. into horizontal baked sand molds. The first bar was cast with the iron as melted; the second, with the iron treated in the ladle with an amount of titanium-alsifier equivalent to two ounces per ton of molten metal.

34. As soon as the bars were cast, time-temperature cooling curve measurements were taken at 5-sec. intervals with the aid of thermocouples extending through the mold into the molten metal. The thermocouples were made of 20-gage wire and were protected from direct contact with the molten metal by a refractory coating containing 10 per cent bentonite and 90 per cent silica flour. Cooling curves were drawn, and the temperature of solidification of each of the two bars were found to be as follows:

Bar	*Temperature of Solidification*
Plain Iron	1996°F.
Deoxidized Iron	1993°F.

35. Metallographic examination of the two bars disclosed that the plain iron contained a mixture of short flake eutectiform and short flake graphite in a dendritic arrangement, while the bar of

deoxidized iron contained a more normal, medium size, flake graphite.

36. These results show conclusively that deoxidation has no significant bearing on the temperature of solidification. The slight difference in the freezing temperature of the plain and deoxidized irons is well within the limit of error of the measurements. When these results are considered together with those of the deoxidized undercooling tests, it is apparent that the effect of deoxidation is related principally to its influence on the characteristics of solidification of any given iron.

CONCLUSIONS

37. The following conclusions may be drawn from the results of this investigation:

1. The graphite pattern of an iron of any given composition has been shown to be governed by the following factors:
   a. the rate at which the iron cools from the liquid to the solid state,
   b. the degree of undercooling which the iron experiences by virtue of its cooling rate, and
   c. the characteristics of solidification of the iron, or its behavior when exposed to a given amount of undercooling.

   The latter factor is an inherent and individual characteristic of any given iron which may be controlled by deoxidation.

2. The influence of undercooling on the process of solidification and graphitization of cast iron can be represented by an S-curve similar to the one originally presented by Bain for the transformation of austenite. Each branch of the S-curve represents a particular type of graphite formation. In the upper branch, flake graphite is formed in a random distribution. The middle branch is characterized by a eutectiform graphite in dendritic distribution. In the lower branch, mottled and white irons are formed. The size of the graphite flakes and the size of the cell pattern outlined by graphite in dendritic distribution, gradually diminish as the temperature of solidification is lowered.

3. The exact nature of the S-curve of an iron is governed by its solidification characteristics. For this reason, irons of different compositions possess different S-curves.

4. The effect of deoxidation on graphite formation seems to be principally related to its influence on the characteristics of solidification of cast iron. Deoxidation results in stretching the S-curve of a plain iron along the temperature axis.

38. The procedures used in this study are perhaps too involved and theoretical as to be applicable to commercial castings. The results do, however, clarify the nature of the reactions involved in the process of solidification of cast iron. Work is now being conducted in an attempt to correlate these findings with wedges and test bars so that the information can be used to the best advantage by foundrymen.

ACKNOWLEDGEMENTS

39. The writers are deeply indebted to Professors W. P. Wood, C. A. Siebert, L. Thomassen, L. O. Case, and E. J. Ash, of the University of Michigan, for their interest, valuable suggestions and constructive criticism. Sincere gratitude is also extended to R. G. McElwee, Vanadium Corporation of America, Detroit, Mich., for the chemical analyses, and to the Metal Processing Department and the Department of Engineering Research for their cooperation and use of their facilities. The time, assistance, and cooperation given the writers by graduate students in the Department of Chemical Engineering also is appreciated sincerely.

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Report of Subcommittee 6c2 on Nomenclature of Foundry Sand Research Committee

To Members of the Executive Committee, Foundry Sand Research Committee:

Gentlemen:

With the advent of the present work on the high temperature properties of foundry sands, now being conducted by Subcommittee 6b7 on the Physical Properties of Foundry Sands at Elevated Temperatures, it was necessary to coin new terms which could be applied to the work of and the results obtained by this subcommittee. Also, some of the definitions of terms which appear in the glossary of the present book "Standards and Tentative Standards for Testing and Grading Foundry Sands and Clays" required revision. To undertake the creation of definitions for the high temperature testing and to revise present definitions used in testing foundry sands, the present subcommittee was organized.

As a result of this year's work the following definitions are submitted for your approval.

Respectfully submitted,

Prof. A. C. Davis, Cornell University, Ithaca, N. Y., *Chairman*
H. W. Dietert, Harry W. Dietert Co., Detroit, Mich.
John Grennan, University of Michigan, Ann Arbor, Mich.

Proposed Foundry Sand Terms

Collapsibility—The ability of a sand mixture to break down under the conditions of temperature, atmosphere and pressure existing during solidification and cooling of a casting.

Note: At a meeting of the Executive Committee of the Foundry Sand Research Committee on May 6, 1940, the above definitions were approved.

Toughness—The ability of a sand mixture to absorb energy.

Unit Toughness—(Toughness number)—The energy absorbed by a unit volume of a sand mixture before fracture occurs.

Yield Strength—The stress at which a sand mixture shows a specified permanent deformation.

Hardness—The resistance offered by a sand mixture to deformation.

Old Definition—Compressive Strength—The maximum resistance which a molded sand offers to a compressive stress.

New Definition—Compressive Strength—The maximum compressive stress which a sand mixture is capable of developing.

Old Definition—Tensile Strength—The maximum resistance which a molded sand offers to a force which tends to pull it apart.

New Definition—Tensile Strength—The maximum tensile stress which a sand mixture is capable of developing.

Old Definition—Shear Strength—The maximum resistance which a molded sand offers to a shearing stress.

New Definition—Shear Strength—The maximum shear stress which a sand mixture is capable of developing.

Old Definition—Transverse Strength—The maximum resistance which a molded sand offers to a transverse stress.

New Definition—Transverse Strength—The old definition is in error because there is no such thing as the transverse strength of a sand mixture. Failure in transverse loading is caused by either shear or tension. The transverse strength of a specimen is usually determined by the tensile strength of the mixture, the dimensions of the specimen and the method of loading.

Old Definition—Dry Strength, Dry Bond Strength—The maximum resistance which a molded sand, dried at 221 to 230°F. (105 to 110°C.) offers to an applied stress before it breaks.

New Definition—Dry Strength, Dry Bond Strength—The maximum resistance which a molded sand, dried at 221 to 230°F. (105 to 110°C.) offers to deformation.

Old Definition—Green Strength, Green Bond Strength—The resistance which a molded sand, while tempered, offers to an applied stress before it breaks.

New Definition—Green Strength, Green Bond Strength—The maximum resistance which a molded sand, while tempered, offers to deformation.

Hot Strength—The strength developed by a sand mixture at any temperature above 230°F. (110°C.).

Hot Deformation—The deformation which accompanies the hot strength.

Thermal Expansion—The increase in volume of a sand accompanying a change of temperature.

Thermal Contraction—The decrease in volume of a sand mixture accompanying a change of temperature.

Retained Strength—The strength developed by a sand mixture after it has been heated to a temperature above 230°F. and then cooled to room temperature.

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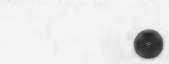

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